S·A·E JOURNAL

PUBLISHED BY THE SOCIETY OF AUTOMOTIVE ENGINEERS, INC.

H. C. Dickinson, President

David Beecroft, Treasurer

John A. C. Warner, Secretary and General Manager

Norman G Shidle, Executive Editor

Vol. 33 AUGUST, 1933 No. 2

CONTENTS

Michigan President Warns Business to "Build Men or Get Out"—Alexander G. Ruthven 13

Stage is Set for Huge International Automotive Engineering Congress 16

Chronicle and Comment 17

The Golden Egg in the Body Builder's Lap—Hal. Holtom 18

Letters to the Editor 22

Behind the Scenes With the Committees 24

Many Companies Sponsor S. A. E. Congress 26

News of the Sections 27

What Members Are Doing 30

New Members Qualified 32

Applications Received 32

Transactions Section Begins

Discussers Question Test Results in Lay Paper, Claiming Wide Differences between Wind-Tunnel and Road Conditions 261

Education—Preparation for or Protection from Life?—C. B. Veal 268

Cageless Roller Bearings Develop High Carrying Capacities—K. L. Herrmann 275

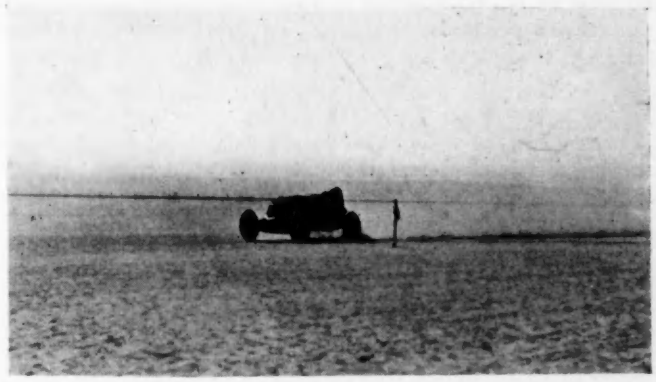
Temperature Effect on Determination of Gum in Gasoline—O. C. Bridgeman and J. C. Molitor 283

Transactions Section Ends

Notes and Reviews 34

Publication Office, 56th and Chestnut Sts., Philadelphia, Pa.; Editorial and Advertising Departments at the headquarters of the Society, 29 West 39th St., New York, N. Y.

Discussers question test results in Lay paper, claiming wide



The Streamlined Car about 100 Yd. from the End of the Measured Mile, the Speed Being Just Over 147 M.P.H. (See discussion by Prof. Elliott G. Reid on page 264)

Differences between Wind-Tunnel and Road Conditions

NEARLY every branch of the automotive industry is represented in discussion which has come in on the paper entitled "Is 50 Miles Per Gallon Possible with Correct Streamlining?" presented at the 1933 Annual Meeting of the Society by W. E. Lay, professor of mechanical engineering, University of Michigan, and published in the April and May issues of the JOURNAL on pages 144-156 and 177-186, respectively.

The following pages present the varied and interesting comments which have been submitted by M. C. Horine, P. Altman, H. G. Winter, E. G. Reid, and Ralph Upson, together with additional comments from Professor Lay based specifically on the points raised by Professors Altman and Reid.

Professor Lay's paper, it will be recalled, was a study of air resistance in terms that the automobile engineer could understand without delving deeply into thermodynamics. The study was suggested by the fact that motor vehicles are now being driven at a speed at which most of the engine power is used to overcome wind resistance, although the greater part of this resistance is unnecessary and can be overcome by correct shaping of the vehicle body.

The paper, as presented, constituted a progress report of research just begun.

Potent Factors Neglected in Many Streamline Tests

— M. C. Horine
Sales Promotion Manager, International Motor Co.

LISTENING to and reading the successive papers on the subject of automobile streamlining, presented during the last few years, I have become more and more astonished at the cavalier manner in which certain factors of seeming importance have been either ignored utterly or blandly dismissed with unsupported assumptions. Were these papers not prepared by authorities deserving of the highest respect and were not the apparently superficial bases upon which their determinations were predicated used in arriving at definite and broad conclusions of sometimes startling nature, these superficialities would not be serious at this stage of streamlining development.

There appear to be rather alarming discrepancies between conditions obtaining in a wind tunnel and those to be encountered on the road. At the 1932 Semi-Annual Meeting, W. B. Stout pointed out that the direct head wind of the wind tunnel rarely is duplicated on the road, and that therefore the results to be obtained from a certain form might be expected to deviate greatly from predictions based upon wind-tunnel studies. He pointed out that the effects of side winds on a streamlined form so developed might prove a serious detriment to safe control. Yet this obvious fact continues to be ignored.

All of the wind-tunnel models which I have seen have had flat, smooth under-surfaces. Crowned fenders are made flat on their under-sides and grille fronts have been represented as smooth planes. I have been told that the deep and cross-

member barred pockets on the under-side of a car offer unimportant air resistances; but, thus far, no one seems to have taken any steps to support this somewhat incredible conclusion.

No car travels 90 m.p.h. with closed radiator shutters, stationary wheels or without movement relative to the road; yet this impossible combination is always present in wind-tunnel tests. The objection has been made that, if the relative movement of the road and the car were reproduced, a moving belt would be required and that the vibration of this belt would upset the results; but where is the experimenter who can say how far such belt vibrations would differ from the effects of road inequalities actually encountered on the highway?

Swiftly revolving wheels not only act as centrifugal blowers setting up currents of air in opposition to the main airflow, but their "Flettner" effect—utilized to drive ships by the Flettner rotor method—must also create reactions upon the airstream which might be expected seriously to upset the simple effects secured with stationary wheels.

To the unavoidably high but utterly ignored air resistance of the radiator—further complicated by the pull of the fan which varies from positive to negative as the speeds increase and by the interference and turbulating effects of grilles, shutters and chicken wire—should be added the under-hood resistance occasioned by the non-streamlined engine with its multiformed accessories, that of the banking of air against the flat dash and that of the turbinated exit through the hood louvers and under the toe-board. Surely these effects have some value, and their airy dismissal seems hardly warranted without at least some investigation.

Constructive Questions on Important Features

— Prof. P. Altman
University of Michigan

I WISH to congratulate Professor Lay and his associates on the fine paper which they have presented and the excellent way in which the data have been compiled.

The first point that comes to my mind is the use of the resistance coefficient K as a comparison of the streamline fineness of a design. This coefficient is a function of the maximum cross-sectional area of the object and, in the case of an automobile, this area is by no means a definite quantity except perhaps where the automobile is of rectangular shape with no projecting parts. In computing the area should we include the fenders, running board, wheels and the like, or should they be omitted? And at what section of the body should the area be taken? If the sides of the car are bulged out, should the additional area be included, or should K be based on the original cross-sectional area of the car? It is possible to think of a case where the area is increased without a decrease in the air resistance or an increase in the passenger capacity; yet, if compared on a basis of K, the model with the larger area would have a lower value of K and would appear to be of better streamline form, while actually this would not be the case at all.

I would like to present for your consideration another basis on which to compute the streamline effect. If a coefficient is desired, why not base it on an area which would be common to all models of a given class and would be independent of changes in body lines? For such an area I wish to suggest the product of the wheelbase and the tread of the car, these being two quantities easily determined and of similar magnitude for cars of the same class. However, at best, the use of a coefficient to determine the streamline effect is not the most easily understood nor does it produce the best mental picture of the accomplishment to the engineer.

The flat plate is something everyone is familiar with and I was pleased to see that Professor Lay took it as his method of comparison between models. I wish to suggest an addition to this comparison; that is, to base the air resistance of a car on an equivalent flat-plate area. Thus we can say that car *"A"* is equivalent to a flate plate of 4 sq. ft., as compared with car *"B"* equivalent to a flate plate of 6 sq. ft. This method of comparison has proved very useful in comparing the parasite resistance of airplanes of similar capacity. For automobile tests, both the value of K based on the area suggested before and the equivalent flat-plate area may be used.

In comparing the various test methods employed, Professor Lay states that the use of a reflection plate without the removal of the boundary layer produces results considerably different from those obtained by the twin-model reflection-method, and that better results would be obtained by testing the model in a free airstream without any attempt to reproduce the ground effect. On this point, our experiences differ considerably.

Tests in our laboratory on ¼-scale models of a conventional car tested at speeds up to 70 m.p.h. showed that, if the model is mounted about ¾ in. above the reflection plate, the results are practically equivalent to those obtained by the twin-model reflection-method; also, that the model mounted in the free airstream gave results about 11 per cent lower than either the reflection plate or the twin-model reflection-method. A study of the properties of the boundary layer and the comparison of our results with those of another laboratory indicate to us that our results are of the correct order and, since they differ so much with the results reported by Professor Lay, I wish to ask the following questions:

(1) How close were the models to the surface of the plate during the test?

(2) What means were employed to prevent the models from touching the plate during the tests?

(3) Were the models tested of conventional form, did they include the wheels and was the axle above or below the lower surface of the car?

(4) At what airspeed is the comparison made between the different methods?

Professor Lay, in his practical streamline form, employs a V-type windshield set at an angle of 45 deg. Are any data available on the effect of glare and reflection due to a windshield of this type? In aircraft work, pilots seem to prefer the flat 90 deg. "degree" windshield, sloping in plan form instead of in elevation. This, I am told, eliminates objectionable glare and reflection. With this type of windshield the roof of the cabin is well rounded as it approaches the top of the windshield and the sides of the cabin are bulged out to accommodate the flow. Tests on an airplane fuselage indicate that this type of windshield, with proper cabin shape and fillets, has about the same resistance as does the elevation V-type windshield.

In the road tests, what methods were used to correct for the effect of cross wind, road turbulence due to surrounding

objects and the like? How uniform were the air conditions between tests?

In the streamline form taken as Model 100, what is the fineness ratio and the scale of the test from which the results are taken? Was this form tested in free air or under the effect of ground interference?

The reason for these questions is that the value listed appears to be high. A good streamlined airship form has a coefficient of about 0.00014 as compared with the 0.00021 coefficient value stated in the paper. Based on the former figure, the ratio of the resistance of a flat plate and airship form of the same cross-sectional area would be 23:1. That is, if the airship had a resistance of 1 lb., the plate would have a resistance of 23 lb. This is a good indication of what the ideal accomplishment may be, and certainly justifies the work undertaken by Professor Lay and his associates on the problem of streamlining automobiles.

Car-Resistance Reduction and Skin-Friction Drag

— H. G. Winter

Aerodynamic-Application Consultant, Briggs Manufacturing Co.

IT has been my contention for some time that the maximum reduction in resistance on the motor car by streamlining, still keeping the vehicle practical, is in the neighborhood of 30 per cent. From Professor Lay's most interesting study we see that, where reductions in drag are high, that is, above 30 per cent, the rear is a 15-ft. tail, a windshield sloping back at 45 deg., or no windshield at all; and none of these means can be called practical. Although he has made tests of many types and combinations, I do not wish it understood that I think he has, by any means, exhausted the possibilities. I think, however, there are enough to explain my point.

There is another reduction here that possibly is not apparent. Model 29 is the 1930 Sedan, a small car in the low-price range. The other models have a much greater overall length, while the cross section is not greatly different. These models have a higher fineness ratio; that is, the length divided by the height or width, or, to be technical, the length divided by the square root of the cross-section area. As this fineness ratio is increased, the drag is decreased. This has been demonstrated by many car manufacturers, using the coasting method and a long and a short car. The longer car coasts farther than the shorter, showing a decrease in the resistance, taking into account, of course, the rolling resistance and inertia of the various parts. In other words, a marked reduction in drag is obtained just by making the cars longer.

If $\frac{1}{8}$-scale models are large enough to be out of the critical Reynolds-number range, then the phenomena noted on $\frac{1}{4}$-scale models tested in the same tunnel certainly should hold true on full-size cars. I am not taking for granted that the smaller models give these values above the critical, for, in Fig. 25 of the paper, there is noted a change in flow, as indicated by the flats in the curves. Several causes for this are possible.

Professor Lay also mentioned "skin-friction" drag. This type of drag, to some extent, is the cause of the air not closing in behind the object giving us form drag. The boundary layer increases in thickness from the front to the rear, tending to increase the width of the wake or disturbed air at the rear. In a recent study of the boundary layer on the dirigible Akron, a 1/40-scale model was used and this boundary layer was found to be approximately 10 in. thick at the rear, or 33 ft. thick on the ship itself.

If we can control the flow of the boundary layer we may control, to a great extent, the width of the wake at the rear. The drag is directly proportional to the width of wake; so, if we can reduce this, we may reduce the resistance.

A great deal of study has been made on this boundary layer, relative to airplane wings. Professor Lay has mentioned that at the surface the velocity of the air is zero, relative to the model, and that skin friction is the energy lost in friction between the various layers of air. This loss in energy is dissipated in the form of heat and cannot be recovered. If, however, we add an equal amount of energy to this layer, or remove by suction the layer as fast as it forms, the flow is made to follow the contour much more closely and a reduction in drag is obtained even on such streamlined members as wings.

We have applied these methods to the present motor-car models with marked success and believe that the reductions in drag possible are of greater magnitude than may be obtained by what I have termed "physical streamlining." A very simple method of obtaining "controlled flow" is shown in Fig. 1. The pressure at the exit in the rear is less than at the entrance. By connecting these two positions by a duct, they tend to become equalized. This then holds the layer of air down at the top and energy is added to the flow at the rear, tending to decrease the reversal of flow of the eddy at this point. The width of wake is reduced and the pressure at the rear is increased, giving a reduction in resistance.

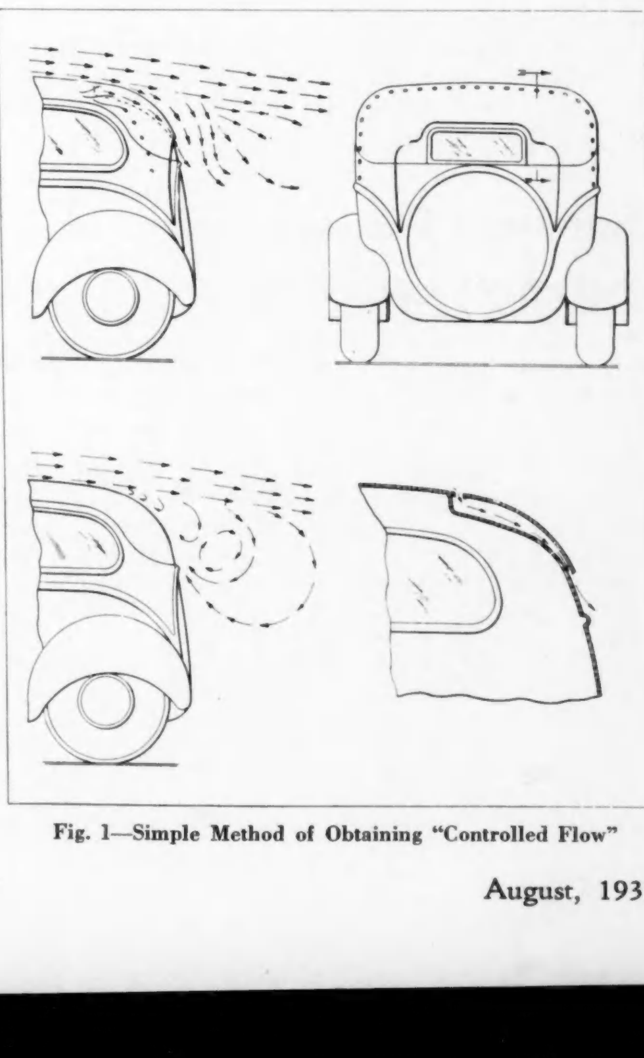


Fig. 1—Simple Method of Obtaining "Controlled Flow"

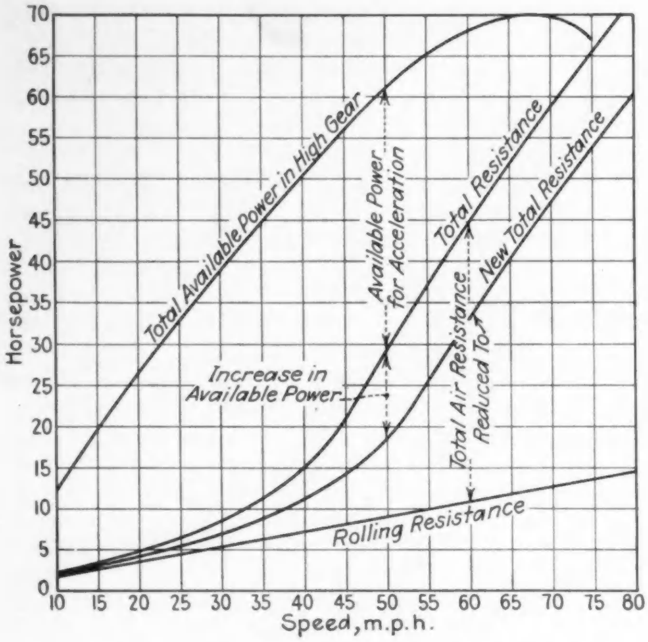


Fig. 2—Savings in Horsepower Required for a Car in the Low-Price Range

A method more or less similar to this on a ¼-scale model of a car in the low-price range gave the savings in horsepower required as shown by the curves in Fig. 2. The increase in available power appears nearly constant from 50 m.p.h. up throughout the speed range and, in this case, it is 12 or 13 hp., which is well worth going after. This is only one of many schemes tried and its efficiency depends on the proper location relative to the radius of curvature of rear corners, the roof line, and rear panel.

Just as the boundary-layer control improves the performance of streamlined shapes, such as wings, so may the performance be increased not only on the present motor cars but also on the streamlined cars.

Dust-Swirl Fuel-Wastage Challenges Car Designers

— Prof. Elliott G. Reid
Stanford University

I WISH to congratulate Professor Lay and his associates upon a splendid example of constructive research. The broad scope of the investigation, the thoroughness of the model-testing technique and the convincing verification of the wind-tunnel results by full-scale trials destine this paper to become classic in its field. If these results should not prove a sufficient shock to jolt body designers out of the rut which has amply justified the drawing of an analogy between the horse-drawn milk-wagon and the modern sedan, I am afraid the situation will have to be given up as hopeless.

To single out the most important item in the paper is not at all difficult; the phrase *"fuel dissipated in dust swirls"* should be a challenge to every automobile-design staff. If we could only see one of those lusty, fully developed B.Hps. being wasted away to the race drivers' "little lazy jackass" by the ravages of the malignant dust swirl, indignation would rise so rapidly that the plague would soon be brought under control. Having had such an illustrated lesson, I want to describe it in support of the views advanced by Professor Lay.

To see a conventional car and one with a streamlined body driven simultaneously at high speed over dusty ground is almost too much to expect. However, I had that opportunity last spring while at Muroc Dry Lake, Calif., during the speed trials of the "Gilmore Special," a Miller-engined racing-car carrying a streamlined two-seater body of my design. The "dust wake" of this car had two unique characteristics: its transverse dimensions were surprisingly small and it resembled the spray from a racing hydroplane in that it appeared to rise and then fall back in place without acquiring any considerable velocity along the direction of the car's motion. At speeds of the order of 150 m.p.h. the dust raised by the race car appeared quite inconsequential when compared with that kicked up by and drawn violently along in the wake of a conventional sedan running *100 m.p.h. slower*. The contrast was so marked that it excited the comments of spectators who would not know a vortex from a spark plug.

The headpiece on page 261 shows the streamlined car about 100 yd. from the end of the measured mile, the speed of that particular run being just over 147 m.p.h. It will be noticed that practically all the dust is raised by the tires, that it hangs very close to the ground, and is not thrust appreciably out to the side; hence it seems logical to conclude that in this case Professor Lay's instructions regarding the "picking up and laying down" of the dust were being followed fairly well.

Rectangular-Box Sedan Affords Example

The best substitute for an object lesson of this kind seems to be afforded by the rectangular-box sedan, Model 2*a*, shown in Fig. 10 of the paper. It looks like a joke but the point gets rather sharp when we learn that its adoption was responsible for an appreciable gain of top speed. The passenger-car body-designer may find some solace in the fact that the resistance coefficient for this model is 0.00113, whereas, that for Seagrave's "Golden Arrow"—built at great cost and after much testing to raise the world's speed record from 207 to 231 m.p.h. in 1929—is somewhat greater, being 0.00127 if we accept the designer's figures. There are, of course, some extenuating circumstances in this case, but the value for the rectangular-box model should cause designers to pause before using what Professor Lay so aptly calls "wind claws."

The agreement between model and full-scale test-results is very fine. It seems unlikely that such close agreement will be found in the case of a more nearly streamlined form, as the magnitude of the scale effect probably will be greater. However, to judge from airplane-model experience, the results of the model tests may be expected to be pessimistic unless the reproduction of full-scale details is rather incomplete. It appears to me that the method of using a single model without auxiliary apparatus should be satisfactory for practically all comparative tests except those concerned with under-body form. I would like to have Professor Lay's opinion on this point.

I have only one fault to find with this work and this criticism applies as well to practically all work of similar nature. The results are presented in the form of coefficients which are not non-dimensional and therefore have to be converted for use with metric units which have an awkward

and easily forgotten number of zeros between decimal point and first significant figure and which suffer the lack of ready physical interpretation of the unit value. This, the so called "engineering system" of coefficients, is an orphan of the American aeronautical engineering fraternity; after more than fifteen years of use in only this country, the system is being displaced by the non-dimensional "absolute system" used throughout the rest of the world. It is to be hoped that the latter system will soon be adopted by workers in the automobile-body field.

In view of the small amount of work done on wheel resistance, I was glad to learn that this problem was scheduled for further investigation. While it seems a minor item if the wheels are to be run in pockets, this procedure may not be conveniently followed in the case of the rear-engine design unless a very broad tail be accepted.

Not a great deal of attention appears to have been paid to under-body form. Perhaps the flat surface with rounded edges cannot be greatly improved upon, but it would be surprising if clearance had not a critical value or if some gain might not be had by raising the under surface toward the rear. In view of probable boundary-layer and scale-effect difficulties, would not the floating envelope be ideal for such testing?

The great difference between the resistance of the "final model, *C*," and that of the "ideal streamline form," centers the spotlight on the question of engine arrangement. The defenders of present practice are justified in their contention that existing design methods and theories will have to be scrapped and that a host of very difficult engineering problems will arise if our present cars are to be turned end for end. On the other hand, the experimental results indicate very clearly that, while the resistance of the typical 1930 sedan may be halved by the application of aerodynamic principles to body design alone, to approach the limit of about one-seventh of the original value any more closely it is imperative to adopt the rear-engine mounting.

The real question seems to be "What price dust swirls? when retailed to the public in quantities of thousands of cubic miles."

Wind-Tunnel-Test Results Need Kid-Glove Handling

— **Ralph H. Upson**
Aeronautic Engineer, Ann Arbor, Mich.

ONE cannot help but be impressed by the extent to which Professor Lay's fine paper is dominated by results from the wind tunnel. This gift from aviation is a strong ally for the progressive automobile engineer. Like standardization, however, it needs to be handled with kid gloves, or whatever kind one wears in a wind tunnel.

First let us lay down the axiom that the most important object of aerodynamic research is to improve performance to the utmost, and only secondarily to tell what that performance will be. It is so easy to make a guess at what looks like an improvement, stick it in the tunnel and get a result. If the tested resistance is lower than that of some previous model, it may mean almost anything, or nothing. This is partly due to the still problematical corrections for ground interference, scale effect, and other unavoidable differences between model and actual car. The different interference corrections given by Professor Lay, though all of them at variance with actual road conditions, differ among themselves to illustrate the general uncertainty involved. And it must be assumed that such discrepancies will not even be consistent for some other model.

Scale Effect Within Wind-Tunnel Range

Unfortunately, the paper does not go into the factor of scale effect, concerned with changes in the type of flow due to differences in size, speed and turbulence. Fig. 25 in the paper, however, shows distinct dips in the two lower pairs of curves, which, if correct, are very clear indications of scale effect within the range of the wind-tunnel conditions alone. As this chart gives the air resistance in pounds per square foot, the coefficient taken for comparison with the full-scale bus-body was evidently computed from the lower part of the lower curve, the value as given elsewhere being 0.00113 as compared with 0.00104 for the full-scale body on the road. The agreement would not have been nearly as good if the wind-tunnel coefficient had been computed, as offhand appears more logical, from the upper part of the curve, which gives the value of 0.00067. It is of course possible that the difference in turbulence between the tunnel and road conditions more than made up for the difference in scale otherwise, and put all of the road-test results into the lower portion of the curve; but there seems insufficient data as yet to be sure of this, particularly as the road-test results did not go below 28 m.p.h.; hence, there may be a large discrepancy in the road interference effect still unaccounted for.

In this connection, it would be of particular interest to have further results from actual road tests. In the meantime, it is amply clear that the drag can be very greatly reduced by attention to various rather fundamental principles of aerodynamics, many of which are brought out at the conclusion of the paper itself; but the interesting thing is that none of them required proof by any new wind-tunnel tests.

To show the extent to which fundamental principles may be successfully applied, I may perhaps cite an experience from the design of the metalclad airship ZMC-2. Structural requirements here made it necessary to depart considerably from previously accepted practice in the shape of the hull. The new shape was determined by theoretical means and what might be termed aerodynamic judgment. With the exception of a minor variation at the tail, only the final result was checked in the wind tunnel. This showed a drag coefficient substantially less than the ideal streamline value quoted by Professor Lay. Such a result is made possible only by the fact that aeronautical engineers have been accustomed for years to thinking in terms of airflow and have had so much experience with problems of this kind as to make it comparatively easy to visualize the general type of flow around almost any conceivable shape; in other words, a man who has specialized on aerodynamics has such a complete picture of the many possibilities involved as to find it unnecessary to make more than a few check tests in most cases. He knows, of course, certain uncertainties still existing that require numerical evidence, but also many more where cause and effect are absolutely dependable.

This makes it possible, from the many variables involved, to pick the proper combination much more surely and economically than can be done by direct reference to a series of wind-tunnel tests. And as ideas are more pliant than mod-

els, they can, in general, be fitted more closely to the automobile engineer's specific requirements. Approached in this way, results such as presented by Professor Lay are a valuable contribution, not so much to direct design as to general knowledge of the subject. Though it cannot in any way replace real aerodynamic engineering, any more than a medical paper can replace a good doctor, this particular paper should be a most important reference and inspiration in a too-long-neglected field.

Lay Amplifies Test Method Data and Answers Critics

—By W. E. Lay

Professor, Mechanical Engineering
University of Michigan

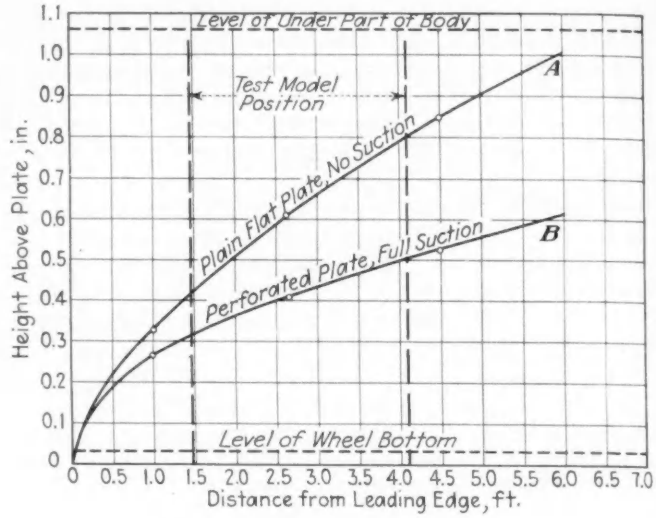


Fig. 3—Flat-Plate Boundary Layer

(The following additional comments were written by Professor Lay after his study of the preceding discussions of his paper by Professors Altman and Reid.)

In regard to the area "A" in the equation $R_a = KAV^2$ a careful reader will find that the cross-sectional area of the vehicle is not used, for the very reason that it is an indefinite quantity. The area "A" is taken as the projected area on a plane perpendicular to the direction of vehicle motion. This area is a perfectly definite quantity for a given vehicle and is nearly constant for any given class of vehicle, such as passenger cars, interurban buses, etc. In defense of its use I can only reiterate the statements made in the paper itself.

The suggestion of the use of equivalent flat plate area is a most welcome one. The resistance of a flat plate is quite definite, the idea is fairly easily understood and presents several advantages from the standpoint of analysis of the problem. Since the ultimate function of a passenger car, for instance, is the transportation of passengers with comfort and convenience and at low cost, a car having a lower equivalent flat plate area than another of equal passenger capacity, comfort, and convenience might well be considered a finer design regardless of its dimensions.

Probably more time was spent on the study of methods of tests than on the actual tests of the models themselves and it is still our belief that so far no one has been able to reproduce satisfactorily the road effect in the wind tunnel.

Quoting from a report made to the Highway Board of the National Research Council in 1931, and published in their "Proceedings" in 1932, "Nine years ago Jaray used a flat plate as a road surface, but we know that such an arrangement will not duplicate the conditions under which a car actually operates. The plate can be built and placed in the air stream so that it will create little or no disturbance of the air flow in the region about the model excepting that it has a boundary layer extending upward toward the model. A layer of air is attached to the plate surface and does not move at all. Succeeding layers above the plate flow at increasing speeds, until at 0.6 in. above the plate the velocity is only 2 or 3 per cent less than that of the main air stream. This type of flow is termed viscous flow and the layer in which it occurs is called the boundary layer. There is, however, a similar boundary layer on the under surface of the model itself and between the two the velocity of the air may be considerably reduced."

Since the results of this study are being questioned, it might be well to discuss it in more detail. The plate was made of two sections of plywood 3 ft. wide by 6 ft. long with an air space between and with faired ends at the front and rear. The plate was 1¾ in. thick with 1⅛ in. air space between the plywood pieces. This plate was mounted in the tunnel and the thickness of the boundary layer clinging to its upper surface was determined at 50, 60, 70, and 80 m.p.h. A pitot tube was made of hypodermic tubing with an inside diameter of .030 in. This was set 6 in. above the plate and the velocity pressure was read. The pitot was then lowered toward the plate until the velocity pressure had decreased 5 per cent (a decrease in velocity of 2½ per cent), this height of the pitot tube above the plate being taken as the practical extent of the boundary layer. These readings were taken at several positions along the plate giving the data plotted on curve "A" in Fig. 3.

About 2000 holes spaced 1 in. apart were then drilled in the upper plywood section. Baffles and a manifold provided with dampers to equalize or control the suction on the holes were then built. A high-speed vacuum blower applied a suction which drew off air from the boundary layer on the surface of the plate. Tests made with the hypodermic pitot showed that the height of the boundary layer had been reduced to the values shown by the curve B. It was not possible with our apparatus to remove completely this slow speed air in the boundary layer. Tests were then made with model No. 28 at speeds from 50 to 90 m.p.h. with the results given in the paper.

The answer of Professor Altman's first question is found on the curve sheet showing the boundary layer calibration for the flat plate. To his other questions, the replies are as follows:

(2) The model was carefully spotted in the correct position with the telescope before each reading.

(3) For the comparative tests of different methods, model No. 28 was used. It had a smooth under surface with the axle covered up. The wheels were, of course, in their housings but extended to within about 1/32 in. of the plate.

(4) Model No. 28 has a flat windshield at 45 deg. angle.

Lights producing objectionable reflections in a car are usually at about the same elevation as the car itself and the sloping windshield carries the reflection below the driver's eyes.

(5) The road tests reported were made in practically still air, at least in so little wind that it would not operate the weather bureau type of anemometer.

The authors are sorry that the value given for the coefficient of the streamlined form is not low enough. The comparison of the streamlined value with that of a typical car seemed bad enough as it was and we wished to be on the safe side.

Thanks are due to Messrs. Hall and Sergayeff for calling our attention to the errors in the two last paragraphs under "Optimum Ratio," on Page 184, S.A.E. JOURNAL for May, 1933. The last figures of the next to the last paragraph should read 24.7 hp. instead of 27.4 hp. In the last paragraph there is no decimal point in 1320 and it should read "At low car-speeds the engine speed computed in this manner becomes too low for good operation at near full throttle so that below 40 m.p.h. the gear ratio may be kept constant and the throttle closed as necessary to obtain the lower speeds."

We can only thank Professor Reid for his many suggestions and his patience in answering our questions. Perhaps this is an opportunity to thank all of those who have written for their many suggestions. It indicates that many agree with us in believing that the reduction of the air resistance of the motor vehicle should receive serious consideration in the design of every new model of vehicle or body.

High Lifting Power for Airplane Wings

A DEVELOPMENT of the last year is the increasing interest and use of auxiliary lift-increase devices, which are giving the pilot of an airplane the means to lessen the minimum flying speed at will. The improvement in appliances for controlling speed has by no means kept pace with the increased speed attained. Brakes on the wheels are supposed to slow down a plane after it has reached the ground, but slowing it down before it comes into contact with the ground is at least as important as are good wheel brakes.

Present-day airplanes have two types of body: One creates lift as a primary purpose and drag as a consequence; the other creates only drag and no lift, or lift in negligible or of only small amount. Lift-creating devices can take the form of wings, rotors, propellers, vanes and, perhaps, even of paddle wheels, or they may some day be a combination of these, but all work on the same basic principle; that is, the creation of acceleration of airflow and thereby of reduction of air pressure on the upper side of the body, and deceleration of the airflow with corresponding increase of air pressure on the under side. The absolute difference between these two pressures constitutes the "lift."

The maximum value of lift determines the minimum horizontal flying speed of a given plane since the equation of lift is $L = K_y S V^2$, in which L is the lift in pounds, K_y is the lift coefficient, S is the wing area in square feet and V is the flying speed. This equation also can be written $V = \sqrt{[(W/K_y S)]}$, in which W is the weight of the plane. Hence it can be seen that a reduction of minimum flying speed is possible only by the use of one of two means; that is, a reduction of the wing loading, W/S, or an increase of the maximum lift coefficient, K_y maximum. The reduction of wing loading means either an increase of wing area, or a decrease of the weight of the plane, or a combination of these.

Wings capable of undergoing an alteration solely by performing some modifications during flight with a view of changing the lift have great theoretical and practical attraction, and the search for means of achieving this end is constantly going on. The experiments which finally brought about the conception of the Zap flap were based on the theory that the lift of an airfoil is obtained by slowing down the flow of the air along the under side of the airfoil and by increasing the speed of the flow along the upper contour of the airfoil.

The Zap flap consists of a flat wing panel which is retractable into a recess on the under side of the main wing. When retracted, it is flush with the under side of the wing and conforms to the contour of the original airfoil. When increase of lift is desired by the pilot for the purpose of reducing the flying speed below the minimum value possible with the basic wing, this panel can be folded downward at its rear end, simultaneously sliding backward at its front end along the wing's under side for some distance, so that the Zap flap trailing edge is always approximately directly below the trailing edge of the main wing. This latter feature is of greatest importance for obtaining the optimum combination of maximum lift and location of center of pressure on the wing.

The operation of the Zap flap is positive and requires very little effort. The panel can be moved by means of racks, chains, bellcranks, or cables and pulleys. A cranking handle or ratchet lever is provided in the pilot's cockpit. The flap, depressed by small angles of about 15 or 20 deg., materially reduces the take-off run and increases the angle of climb shortly after take-off. Maximum rate of climb is usually obtained with the flap fully retracted.

The layout of the operating linkage is of great importance as it determines directly the resulting opening and closing forces at given airspeeds. Tests indicate that the flap does not increase the lift on account of its own area and shape, but mainly by stimulating a change of airflow around the main airfoil. The flap produces not only an increase of lift but also a high increase of drag as compared to the basic airfoil. A plane with Zap flaps can be brought over the edge of the flying field at about a 1000-ft. altitude and can be landed from there at the middle of the field. The lift increase obtained by use of the Zap flap depends upon the characteristics of the basic wing. Thin wings with small mean camber are benefited to a higher degree than are thick wings with high camber. In actual flight, the values of lift increase are considerably higher than are apparent from wind-tunnel results. The actually measured minimum flight speeds are by 10 to 20 per cent lower than the speeds calculated from wind-tunnel tests.

The field for the use of variable-lift wing-arrangement is comparatively freshly ploughed, and the next four years undoubtedly will show that such devices will play a very important role in the development of faster, more economical and safer aircraft.

—Excerpts from a paper presented at recent meetings of the Metropolitan and of the Baltimore Sections by A. A. Gassner, chief engineer, Zapp Development Corp.

Education— Preparation for or Protection from Life?

By C. B. Veal
Research Manager
Society of Automotive Engineers

LIFE is a cruise in which each of us is the pilot and sailing master of his own ship. For this supreme adventure no man can chart your course, but philosophers in all the ages have contributed to "The Pilot's Guide." These "Aids to Navigation" make civilization.

What is the port? What the measure of attainment? Is it money earned, wealth acquired? Is it eminence in your profession or in the world of general affairs? To me the objective is a much more personal and relative thing. It is the extent to which each of us develops the talents entrusted to him and puts them at the disposal of his fellow men. Such is the search for happiness—which is life.

Every one wishes to be happy. To be happy is to live. Timothy Dwight says, "The happiest person is the person who thinks the most interesting thoughts." Thus happiness is something from within and not from without. It is more than mere contentment or rejoicing in possessions. A certain Oriental king who was very unhappy called a philosopher to him for advice. The philosopher told him to find the most contented man in the realm and to wear this man's shirt. After long search the king found this man—but he had no shirt!

Function of Education

If this be the plan of the edifice, the foundation must cover a much broader scope than is usually embraced in the term "education." The knowledge gained from books and teachers is of service only if it is appraised at its true value, as one of the weapons to be used in fighting your battles. If you regard it as an impregnable fortress behind whose shelter you will be protected from the forces of adversity and competition, you will find yourself on leaving college in the same fix as the snail when he leaves his shell behind him. Science is a powerful force, and your study of it will yield worthwhile returns, but it will not in itself lead to a happy or complete achievement in living. To live completely we must understand not only the laws of nature but also the laws of human nature. The world of affairs is not governed by the orderly rule of science; it is a conglomerate of human beings. To deal with it effectively you need more than scholastic ability, and it is on some of these extraneous qualifications that I wish to dwell most strongly. For you must begin now, in your period of preparation, to equip yourself with these other weapons—no one else can do it for you. They are of three types: First, those you need *as an individual;* second, those you need *as a member of society;* and finally, those you need *as a professional man.*

Importance of Physical Health

The individual's duty to himself heads this program. This does not conflict but strictly accords with the principles of altruism. Water cannot rise higher than its source; you cannot give out more than you possess. I doubtless am even a bigger bore than Polonius and worthy of as unhappy a fate, but I thoroughly endorse his dictum as a supreme rule of conduct, "This above all, to thine own self be true."

What is the fundamental basis of this first item of our program? This: We are primarily animals—we must be successful animals. Observe the laws of hygiene and follow a program of physical development, so as to conserve health and build up a reserve of strength. Only then shall we have the endurance to survive the storms that beat around our ship and the ability, if necessary, to rebuild after a wreck.

Emphasizing physical well-being does not belittle the value of moral fortitude—far from it. Many are the physically unfortunate whose handicaps have been a support, a spur, urging them on to achievement by sheer force of will.

After physical, comes mental health. Perhaps what I urge here is heresy; it is that you do not bind up your life exclusively with your job. Increasing specialization in industry has made most jobs too narrow in scope to give full play to the varied capabilities of the normal man. In the older days of decentralized industry a man's job might present a broad variety of tasks and contacts. In the highly developed hierarchy of today, an engineer's task for years may consist in studying in minutest particular and with meticulous accuracy some detail, an important part of a whole, but, in itself, of little significance. Consequently, each of us needs for his fullest development some activity, outside that in which he earns his living, to give additional scope to his constructive ability and to bring him the satisfaction of creation and accomplishment.

Among eminent engineers whom I have been fortunate to know, this interest in a field outside their professional sphere is a strongly marked characteristic. For example, one engineer and executive, passing successfully and successively through the stages of accomplished musician and connoisseur of art, is now studying sculptoring; an investigator and inventor in the field of mechanical engineering has selected biological chemistry as his secondary activity; Prof. Karapetoff,

THIS paper was presented at a "Father and Son" meeting of the Cleveland Section on April 10, 1933.

Talking directly to the young man still in school or college, Mr. Veal drives home point after point equally applicable to older and more experienced engineers. As his text, he uses a sentence of Elbert Hubbard's: "Blessed is the man who has found his job." He applies universal truths to present conditions and sketches the means by which personal happiness and success may be achieved.

As a measuring stick of success, Mr. Veal suggests "the extent to which each of us develops the talents entrusted to him and puts them at the disposal of his fellow men." Then he shows how physical health aids in the fulfillment of that objective; the part played by hobbies and avocations; the need for meeting social obligations; the practical chances existing for young engineers; the personnel needs of research; the opportunities in operation and maintenance work and the possibilities for engineers as industrial advisors.

of Cornell University, who is eminent as a scientist, engineer, pianist and cellist, was recently heard on the radio program "Music Is My Hobby." The president of this Society, a physicist of high standing, has for years combined with this activity fruitful investigations into the economic aspects of society.

View the career of Leonardo da Vinci, painter, sculptor, architect and engineer; Goethe, lawyer, student of medicine, statesman, theatre-director, practical political economist, scientist, poet, dramatist, philosopher; George Washington, farmer, engineer, statesman, soldier, capitalist; Thomas Jefferson, farmer, engineer, architect, statesman, diplomat; F. Hopkinson Smith, engineer, painter, author; and innumerable others. Among friends, like myself, hopelessly addicted to sailing, I count engineers, merchants, lawyers doctors, chemists and even college professors.

David E. Ross, Chairman of the Board of Trustees of Purdue University and a successful engineer and executive, in a recent address raised a question as to the next development in an industrial system where all the waking hours of a man's life was not utilized in providing for necessities. He said, "I am going to predict that when you get that solution it will be an education of how to spend leisure, whether leisure be a cultural leisure or not; whether leisure will be vicious or not. What will people do with their extra time? If it is a cultural leisure, there is hope for this country."

Practical considerations also urge that you have interest outside your work. In these days of complex industrial organization a job is dependent on many extraneous factors, factors wholly unrelated to your ability. You may be filling your job completely, and yet wake up one morning to find, as many men of my acquaintance have, that forces entirely outside your control have demolished it. Then, if your whole being has been concentrated in it, you may find yourself lost in a world which has no meaning for you. For the sake of your own mental health and well-being, you must maintain a wider contact with realities through cultural, constructive and humanizing hobbies.

Advantage of Hobbies

Another serious advantage of hobbies is that they develop mental spheres and physical abilities that may serve as welcome commercial reinforcements in times of stress. You probably have heard Mr. Kettering tell his story of the frog that was mired in a pool of mud. He besought a passing deacon to help him out, his condition was deplorable, he had been there three days and would probably starve to death. The deacon was touched, but it was Sunday morning, he had on his best clothes, he could not usher in the congregation and pass the collection plate with his clothes spattered with mud. He promised the frog to help him out on his way back from church. Returning, he found the frog out in the middle of the road, hopping briskly along. "See here," said the deacon, "I thought you couldn't get out of that hole." "So did I," replied the frog, "Until a snake got in there with me."

Psychologists have said that people in general do not fully develop or live up to their intellectual capabilities. The snake does not come around often enough. My late partner, C. M. Manly, whose achievements commenced in his work with Langley on aeronautics and continued throughout a fruitful life, used to give this advice, "So conduct yourself that at any time you can tell the whole world to go to hell." In its exact form, his advice now is a little superfluous, since the world has already gone to hell, but in principle it is still valid—that every one should have sufficient extra resource to fall back upon—to be independent.

My point is this—do your work well, give it the best that is in you, but for the sake of mental balance, also enjoy suitable recreation and cultivate other abilities that will not only enable you to do your work better, but may stand you in good stead in time of need.

Social Obligations

After you have fulfilled your duty to yourself in establishing your physical and mental well-being, you are in a position to meet your obligations to others. If human beings, basically, are animals, they are also social animals, and equal emphasis should be placed on the adjective as on the noun. You will need to develop consciously the tools through which social contact is maintained, for the sake both of your work and of your life outside your work.

One of the most elemental of these tools is the ability of self-expression. Engineers have eternally to listen to the reproach that they cannot make themselves understood. The content of their thought is too often a highly specialized subject with which they are accustomed to deal in a vocabulary peculiar to it; they must humanize their thought and make it articulate in terms intelligible to others—their assistants, their co-workers, their superiors. I believe, too, that engineers, because of their characteristic abilities and training, have those habits requisite for adequate expression—close observation, careful analysis and accurate reporting. To utilize these capabilities, we must also command the mechanics of the English language. I know a young chemical engineer who is as

keen, but no keener, than his associates; who has as good a training as they, but no better; but of all the men of his department he is being selected for a position of responsibility because he has been able in his reports to represent himself and his work adequately to his superiors.

You must study yourselves and your associates, to find out what are the qualities in you that prejudice them against you, and through what avenues you may best approach them and make contact with their intelligence and interest. However, in your effort to work effectively with both superiors and subordinates do not mistake pleasant agreeableness for helpful cooperation. Do not become a "yes man" and above all do not learn to lean on others or permit your future to depend on the acts of others.

I had the privilege this last summer of engaging in a cooperative test project with about thirty engineers especially trained and expert in the particular field of investigation. They were also, for the most part, representatives of large organizations, where an important function was to get along with others in their company. Even above their technical ability which was decided, the most impressive characteristic of these men was their ability to see the viewpoint of the other man, to present their own clearly and without antagonism, to argue through a point persistently but diplomatically, to see the flaws in their own reasoning and to arrive at justifiable and reasonable compromises. It is a part of my work naturally to attend many conferences and committee meetings where reports are heard, matters of policy decided upon, and plans for future projects perfected. Here can be seen most clearly the importance of making one's self clearly understood, of comprehending the viewpoint of others, of finding the best approach to individuals, of sensing the trend of sentiment, of knowing when to talk and what to say and when to keep silence gracefully.

Hobbies

"Do your work well.

"Give it the best that is in you, but for the sake of mental balance enjoy also suitable recreation and cultivate other abilities that will not only enable you to do your work better, but may stand you in good stead in time of need."

An instructor of mine used to emphasize particularly the value of human contacts. "It is not what you know, but whom you know that counts," he used to say. Our social activities should not be held down to our immediate personal or job contacts. We must assume our full responsibility as members of a human society, and participate in forming those economic customs and conditions that so strictly limit our horizon.

We, as engineers, must not confine our activities to our profession and let the world govern itself as it will; our training and position in society place on us a responsibility for the welfare of the community.

Moreover, the consequences of any neglect of general civic and economic duties are serious. The safety of our investments depends upon our knowledge of business outside our own direct sphere. Our general security depends on the economic condition of the world. The system that we have was not forced upon us by a *deus ex machina;* it was developed by men, and will not be changed except by the combined education and activity of all of us. We cannot leave it to a legislature to legislate us into prosperity, any more than a legislature could legislate us into morality. Only an intelligent and active public opinion, to which we must contribute our due share, will bring salvation.

Opportunities for Young Engineers

Only after a man has performed his duties to himself and filled his general social obligations is he justified in concentrating on the specialized demands of his profession.

Is the saturation point reached in the engineering profession? Is the supply of engineers being swelled far in excess of the probable demand? The answer depends in part on how you define engineering. I like best the definition inscribed on the walls of the Engineering Societies' Library in New York: *"Engineering, the art of organizing and directing men, and controlling the forces and materials of nature for the benefit of the human race."*

Enrollment in engineering colleges, including graduate and special students increased approximately 40 per cent in the 10 years between 1921 and 1931, from 57,017 to 78,685. The threat of surplus supply seems much less imminent, however, if the number of those receiving degrees is taken as the criterion. Undergraduate engineering degrees were awarded to 7154 during the term 1921-1922, while the number estimated for this year is about 9500, an increase of about 2300. Furthermore, much of the increase in enrollment has occurred since 1927-28 in accordance with the general tendency for young men to attend college in greater numbers during times of depression when they cannot get positions. If past history repeats itself, a recession in technical college enrollment will be felt when and if business picks up again.

If the demand side of the picture be painted in the colors provided on the palette of 1931, a gloomy scene is presented, as estimates of the proportion of engineering graduates placed in jobs that year varied from 20 to a little less than 40 per cent. For a brighter view our gaze must be turned back to 1929, when practically every engineering student stepped from the classroom to a job, when the demand for capable and willing graduates was said to exceed the supply, when business organizations apologized to colleges for cluttering up the campus with scouts for promising industrial human material.

Whether and when this happy day will return again is a dangerous subject for prophecy. Carefully disclaiming all personal responsibility, I merely put before you some more cheerful views etched by others. The question "Do you feel the need in your industry of a greater number of employees having had technical college training?," put last year to a group of business executives, brought back from 53 a categorical "Yes" and from 38, "No." For every engineering student there are at present 2.2 industrial establishments and 82 industrial wage earners. Five years ago, when perhaps conditions justified a fairer conclusion, the proportion of engineering students was slightly less, there being one student to each 3.2 industrial establishments and to each 140 industrial wage earners. The normal requirements of manufacturing industries for engineering graduates is quite consistently estimated at 2.2 to 3.0 per cent of the total forces. This is the conclusion drawn in a report of an investigation made in

1931, which contains the further statement "Taken as a whole, this potential demand is perhaps one-third supplied."

Numerous excellent surveys show what opportunities and rewards the engineering profession has offered college graduates of past years. Briefly, and in broad outline, these indicate that 65 per cent of those of you who are graduated will remain in the type of engineering covered by your course, 10 per cent in a line closely associated with it, 13 per cent in a non-associated engineering field, and 10 per cent will take up non-engineering work. Ten years from now 1.5 per cent of those of you who are graduated may expect to be consulting engineers, 9 per cent engaged in designing, estimating and drafting; about the same proportion in construction, operation, testing and assistant engineering work; 11 per cent teachers; 38 per cent major executives; 12 per cent salesmen; and 6 per cent engaged in clerical and miscellaneous work. Your earnings will present a steadily ascending curve, until 10 years after graduation those who attain average success will be earning $4000, and 20 years later $7000; while the corresponding figures for those of exceptional ability and good fortune will be $7500 to $30,000. That an engineer may look forward to a long period of fruitful activity seems to be indicated by these surveys. While industry, neglecting technocracy's discredited pronouncements, is reproached with retiring the general worker at too early an age, it appears to retain its engineers with little reduction of reward even through the 60's.

Engineering Requirements of the Future Research

What distinctive features, if any, mark the present market for engineering talent?

In attempting to answer this question, I shall try merely to indicate what seem the logical responses to the crying needs of the present economic situation. These seem to me the most distinctive threads of the industrial pattern today; an efficiency in production which enables 60 per cent of our people to raise enough food and make enough manufactured articles to satisfy the needs of our present standards of living; concentration of two-thirds of the nation's business in the hands of 600 corporations; the possession of scientific knowledge and mechanical inventions far outstripping the ability of the ordinary man properly to utilize and enjoy them; and, finally, a temporary hesitancy in progress. Like some clumsy, but powerful, prehistoric monster, the industrial world seems to be pausing, undecided, awaiting the impulse to determine the direction of its slow-moving but irresistible forward march.

One of the first needs indicated in this picture is for research that will discover new products or new uses for old products. The injection into the sick industrial system of some new product of particular appeal has in the past proved a powerful stimulant toward recovery.

The success of certain new activities stands out brightly in the present general gloom. Cellophane has undoubtedly achieved wide distribution. The youngster aviation is being royally treated even by a depression-sobered America. The passenger traffic of air lines in this country last year totaled 145,000,000 miles, an increase of 21 per cent over the previous year. The volume of air express business has trebled in two years. From 1929 to 1932 passenger traffic on airlines increased 210 per cent, while that on the railroads was falling off by 46 per cent.

Industry needs research in its present sickness; it also has in itself the elements for the cure. Organization of business into large units amasses reserves of capital to pay the bills of research. Continuity of existence of large corporations enables them to play a waiting game while new ideas are being born and perfected in their laboratories. Of course, big business is not the sole or indispensable support of research, but it is a powerful ally.

How actual conditions as to the importance and present aims of research bear out these theoretical considerations may be ascertained from some recent surveys made by the National Research Council. From these it is estimated that three-quarters of a million dollars is spent for research each working day in the United States. The number of industrial laboratories more than tripled itself from 1920 to 1930, from 500 to 1600. In addition, industrial research staffs are maintained by more than 100 universities; trade associations in 70 industries spending annually $15,000,000 in research and Government bureaus, notably the Bureau of Standards, perform with distinction in the field of scientific and industrial investigation.

Leading manufacturers estimate the ratio of profit to amount spent for research at from 100 to 300 per cent. Research activities find their way into the annual reports of large companies, along with finance, markets, operations, labor conditions, general business conditions and outlook. Research does not seem to be depressed. In the most recent of surveys made by the National Research Council, 309 laboratories, representing 19 industries, reported on their research expenditures. Of these 51.3 per cent had increased their expenditures during 1931 as compared with 1929; 18.7 per cent had made no change, and 30.0 per cent had decreased them. A more justifiable comparison is the proportion of research expenditure to sales. Of the reporting companies 75.3 per cent had increased this proportion, 14.3 per cent had made no change, and only 7.5 per cent had decreased it. The changing aims of industrial research may be seen by contrasting conditions in 1928 and 1931. In 1928, 31 per cent of all the companies reporting to the National Research Council placed the major emphasis in their research programs on the reduction of production costs, in 1931, 19.4 per cent; 1928, 34 per cent on the improvement of quality of product and service; in 1931, 37 per cent; in 1928, 20 per cent on the development of new fields of application and 15 per cent on the development of by-products or new materials, or 35 per cent for the general field of the development of new ideas. In 1931 this general field accounted for the major activities of 43.6 per cent of the reporting companies; 37.7 per cent

To a Young Man—

contemplating engineering as a career, Mr. Veal suggests:

(1) Review carefully your own inclinations and abilities;

(2) Study fundamentals; do not specialize in college;

(3) Learn how to continue to learn.

new products; 4.5 per cent new fields of application, and 1.4 per cent by-products.

In bringing a new product into the market fundamental research is followed by experimental design and development; then comes production, marketing and distribution, in all of which the engineer plays an important part. Much has been written and much remains to be written about the technically trained man's inter-relation to all these functions and certainly those industrial concerns of the future will be most successful which best utilize the engineer in these interdependent activities. However, if industry is to flourish its products must be utilized and it is in this utilization that the engineer may expect to find the greatest increase in demand for his services.

Operation and Maintenance

The field of operation and maintenance, I believe, will call a larger proportion of you than formerly. To quote from a recent bulletin covering an investigation of the field in industry for graduates of colleges and technical institutes, "With the rapid shift toward higher standardization and automatic processes, the total force requirements tend to diminish, but there is a striking rise in the proportion of staff experts and of highly trained technicians and supervisors. ***Engineering and sales staffs are fairly well recruited from this source (engineering colleges); production, operating and maintenance staffs most inadequately." Some educators feel that this sphere properly belongs to the graduate of the technical institute; I believe that, to a large extent, it demands sufficient breadth of training to require the services of the engineering graduate.

In the industries with which I am most familiar, the automotive, aircraft and petroleum industries, the conviction increasingly gains ground that the job of operating and maintaining large fleets requires sound engineering knowledge. Let me mention a few subjects with which a man in such a position will come into intimate contact: the chemistry of gasoline and lubricating oil, engine design, strength of materials, the economics of standardization, routing and repair practices, the psychology involved in the management of men, the fits and tolerances that must be maintained to keep a machine in operation, the mechanics of time and motion study, the control of inventory and flow of material, and many other subjects of such broad significance as to bring into play all the intelligence and training of an engineering graduate. Perhaps nowhere does a comprehensive working knowledge of men and materials and the forces of mind and matter stand a man in better stead than in the public utilization of the products of engineering.

General Industrial Field

The third field that current conditions are preparing for the sowing of engineering talent is so broad that only its general outlines can be sketched in. The role of industrial adviser has in the past been played by the business man; in the future the part will be assigned with increasing frequency to the engineer. Here technical knowledge and training are of value not for their own sakes, but as a basis for judgment to be exercised over a vast sphere of diversified industrial interests.

That this field should be placed within the scope of engineering is only a logical development of the ever-continuing growth of our profession. Engineering was at first only an adjunct of war. In the travail of the industrial revolution, the mechanical engineer was born. Railroad building and the associated activities of the early nineteenth century gave modern civil engineering its place in the sun; chemical engineering was a product of the last century and electrical engineering is still young enough to feel growing pains. In response to an economic need, industrial engineering is commencing its forward surge; and the engineer is being called on to use his abilities as analyst and builder in the solution of business problems.

An example of the variety of topics that might be comprised under this heading is a list of the problems handled within a comparatively short time by one consulting engineer. This included, among other items, the formation of a theatrical policy to combat motion-picture competition, the advisability of a chain store going into the candy business, the policies of foreign governments, the consummation of railroad consolidations and the earning possibilities of toll bridges. Among specific types of work distinguished in this general sphere are time study, sales engineering, financial advice to banks on loans to industrial concerns, cost analyses and budget and inventory control.

Educational Preparation

You will doubtless wonder what training will fit you for so broad and varied a calling as is indicated even in my fragmentary discussion. Institutions of learning are constantly subjected to criticism. This is wholesome evidence of the interest that the community is taking in a force which is absorbing a constantly increasing number of persons for an ever-growing period of time. But ample evidence has been collected to show that engineering colleges do not stand weakly aghast at the magnitude of their problem; they are constantly adapting themselves to the needs of their students so as to perform adequately their share in fitting graduates for their life work.

Investigations to ascertain the relation between a man's academic and professional performance have been made by educational and technical societies, industrial organizations and individuals. They have used as evidence the information given by engineers themselves, corporation reports and the records of Who's Who in Engineering and Who's Who in America. Both the amount of salary received and the extent of professional eminence have served as criteria of success. From these studies the conclusions may be drawn that engineering graduates value their college training highly, that the correlation between scholastic and professional achievement is high, and that the more years of education a man has the greater his chances for success are.

Granted that engineering colleges, to the full extent of their sphere, are placing at your disposal facilities to assist you in preparing for your life work. What use shall you make of them? What shall be your basis of selection?

The first thing I would suggest your doing is to review carefully your own inclinations and abilities. Make sure, in so far as you can, that you really desire to be an engineer and have the qualities necessary for success in that field. The rate at which students drop out of engineering colleges is high, and is seemingly growing higher. Less than 30 per cent of the students entering these colleges are graduated in four years; less than 40 per cent of them ever receive their diplomas. Contrast with this the fact that about four-fifths of the students entering medical schools successfully complete their courses. More engineering students are dropped for scholastic failure than for any other single rea-

son and the major portion of these scholastic failures are attributable to poor preparation and lack of interest and ability. Your own salvation demands that you remain in an engineering college only if you are fitted for the work; the disappointment and loss of time involved in attempting to master subject matter outside your natural interest and capabilities is too great.

Perhaps one explanation for the lower rate of elimination during medical courses is that so many prospective medical students are eliminated even before they begin. During the school year 1929-1930 approximately 14,000 persons made application to medical schools; of these only 7000 could be accepted.

Aptitude tests are being studied and applied generally only in medical schools. Only 13 out of 103 engineering institutions are using aptitude tests as a basis of admission. The major portion, 84, admit applicants on the basis of certificate from high school or college board examination, although the evidence is said "to be conclusive that admission by certificate without supplementary selective requirements results in the admission of large numbers who are not qualified successfully to pursue an engineering program of four years' duration."

"Study Fundamentals"

My second caution would be, "study fundamentals; do not attempt to specialize in any one narrow field of engineering." The body of scientific knowledge is so great that to acquire a mastery of only its rudiments is a task worthy of all your efforts. Specialized knowledge on any one type of engineering practice should be sought in either of two places: in the technical institute if the object desired be manual dexterity or practical ability; in the graduate school if more theoretical or fundamental learning be the goal. Ample evidence is available that educators, engineering graduates and practicing engineers endorse the view that your primary object during your college course should be to acquire a foundation of knowledge of fundamental principles and methods. "In general, actual specialization should be postponed to the years after graduation and be undertaken either in the graduate school or in connection with introductory experience."

For the future research engineer this study of fundamentals is of particular importance. Mathematics, physics, chemistry, mechanics and other theoretical subjects must be the dominant features of his program. But of equal weight with the material of his courses is the spirit with which he pursues them. He must be actuated by zeal for the truth without thought of personal gain.

A more practical attitude is demanded by the second type of engineering to which special mention has been given, that of operation and maintenance. To the student who is looking forward to this kind of occupation, I would say, "Get into grips with your job as early and as often as you can. To as great an extent as is compatible with your health and well being, use your vacations in getting work in this field, no matter how low in the industrial scale such work is. You will then find out what knowledge you really need to have."

For activity as an industrial advisor the necessity for training in economic and cultural subjects seems strongly indicated. Since engineering education threw off the shackles of the apprenticeship system it has gone through a course of increasing liberalization and is preparing to meet this requirement. The number of engineering colleges giving courses in industrial engineering, for instance, has increased from 6 in 1914 to 35 in 1931.

The study of cultural subjects yields returns. This is indicated by the fact that 60 per cent of the graduates questioned on this point in a recent investigation indicated their belief that cultural studies were of considerable value to them. In another investigation, an analysis was made of the earnings of 31,000 graduates of land-grant colleges, including all types of courses, to determine which courses provide the best equipment for life. No claim is made for conclusiveness in the findings on this point, but the comments on it are interesting. The report reads in part, "The comparison between Arts and Engineering graduates now in business does give some quantitative evidence bearing on the recurring question of the relative values in cultural and technical training. Apparently from the economic point of view, where technical training is thought to have its strongest case, the advantage actually lies with Arts and Science or cultural training."

Another piece of evidence in favor of cultural education is found in answers to a recent questionnaire sent out by Ohio State University. In these 81 out of 97 business executives said that there was need for more cultural training and a wider social outlook among industrial executives.

But perhaps the most important thing for you to learn in college is how to continue to learn.

> "Why, then, the world's mine oyster,
> Which I with sword will open."

are the words Shakespeare puts into the mouth of one of his characters. But the engineering diploma is no such sword, nor is it a certificate of universal learning. In securing a job or in keeping it, your diploma merely gives you the benefit of the doubt over the man without an engineering degree.

You must first of all retain what you have learned and the best way to do this is to practice it.

You may have heard the story of the farmer who was approached by the enterprising solicitor for an agricultural magazine. "On this first page," he said, "we tell you all about raising poultry, how to select feed and treat poultry so as to increase both the egg production and the eating quality. Now wouldn't you like to know about that?" The farmer continued to chew his straw and shrugged his shoulders in the negative. "On the second page," continued the solicitor, with even more persuasiveness, "we tell you how to raise cattle better, how to increase the milk yield and make better beef animals. How about that for a valuable department? Aren't you interested in that?" "No," grunted the farmer. "Well," said the slightly exhausted solicitor, "our next department is about rotating crops, fertilizing, and in general how to make the best out of your ground. This surely will interest you." The farmer still maintained a negative attitude. By this time the solicitor was exasperated. "What's the matter with you," he said, "Don't you want to know how to become a better farmer?" "No," said the farmer, "I already know how to be a much better farmer than I am."

Don't make this mistake. Be as good an engineer as you know how to be, and remember that an important law of learning is that a student tends to retain what he is taught in proportion to the frequency with which he uses it.

In addition, continue ceaselessly to increase your knowledge both of professional and cultural subjects. With science at its present accelerated rate of progress, you must keep everlastingly at it if you are to keep pace with your profession. And you must furnish your mind well from the vast storehouse of human knowledge if you are to be a well-rounded

man. You can no longer depend solely on your job to educate you, as the intense specialization of industry tends to narrow down individual jobs, especially those usually assigned to beginners, to some particular detail.

Young men who graduate from college in times like these may have an anxious period of waiting and searching for work. This search for work, if rightfully viewed, is also an educational process; you may learn much from it. If you cannot find work, remember that while you may have some excuse for not finding a paying job, you will have no excuse for idleness. Utilize your time to make of yourself, systematically, a better engineer and a better man. Virgil puts into the mouth of Æneas, when encouraging his men in a difficult situation, this advice, "Persevere and preserve yourselves for better circumstances." But you should do more than preserve, you should improve your faculties, so that when your opportunity comes, as it will, you will be prepared for it.

Rail Regulation Fundamentals Not Applicable to Trucks

REGULATION of transportation as we know it today was undertaken when the railroads had a practical monopoly of transportation service. It was designed primarily to protect persons and localities from unreasonable and discriminatory charges, from rebates and other practices which aroused public clamor at the time and which were possible only because railroad transportation was a monopoly in fact. This situation no longer exists, and has not existed for many years. Neither railroads nor automobiles have any monopoly whatsoever. In other words, the very cornerstone of transportation regulation in this country has been eliminated. The structure stands on false masonry. Certainly a new foundation cannot be justified by any fancied motor car monopoly of transportation. For it is of the very essence of truck and passenger transportation that it does not lend itself to transportation monopoly.

When regulation is proposed for the automobile would it not be worth while to study some of the effects of regulation on the railroads to help us determine whether similar regulation of the automobile would really be in the public interest? Aside from the fact that the railroad industry, unlike other industries in the same condition, is forced to operate an overexpanded plant to the extent of perhaps 40,000 or 50,000 miles, the chief evil of regulation is that it deprives the owners of the business of the freedom to make two decisions that are vital in any business; the price of the product and the quantity to produce, and thereby deprives the public of those standards or service and value which are only fully developed under keenly competitive conditions.

It is a remarkable tribute to the railway managers of the country that they have done as well as they have, restricted as they have been by the enervating hand of bureaucratic governmental regulation.

And it is quite within the bounds of common sense to question whether the conditions which brought about the present system of regulation might not have been dealt with a great deal more effectively by the free play of competitive forces than they have been by commissions, state and federal, whose authority has exceeded their responsibilities and under whose influence the railroads have become a source of concern to their owners, their employees, and to the public.

Since more stringent regulation of automotive transportation is now being advocated, allegedly in the public interest, it is pertinent to pursue briefly an inquiry into the effects of regulation previously applied to our railroad transportation system.

If we are to judge a policy by its fruits, the conclusion is inescapable that Government regulation, as we know it today, and as we are asked to consider it in terms of the automobile, is largely unwarranted and mostly harmful in its effects. And if the operation of an automobile must be wound around with the red tape of Government regulation of its traditional character, it will both add to the cost of living of the people and be of no particular benefit to the railroads, the automobile, or the public.

One of the difficulties about regulation is that once entered upon it is almost impossible to halt. First we start out to prevent discrimination. Then we have to establish rates. Then we have to know what the property is worth and what rate to establish to satisfy the investor. Then we have to forbid some one from entering the business because that would disrupt the system already established. And so on, until an unnecessary, unwieldly bureaucracy has been built up, sending out its tentacles in every direction.

It is advocated in some quarters that the rates charged by truckers be regulated by law. On account of the individual nature of truck haulage this rate regulation would be difficult. But let us look at the railway rate structure and consider if it is desirable to risk the imposition upon the truckers of such an unscientific, complicated, and confusing thing as regulation has developed in the case of the railways. One of the maxims upon which railroad rate making has been based under this system is "to charge what the traffic will bear." This means carrying some freight for less than the total cost of transportation.

The argument is that if an existing volume of traffic yields an income to cover all fixed charges, then additional traffic may be secured if it covers out of pocket expense. Rates are established which are below the total cost of transportation to meet boat competition, to meet competition from a rival railroad or to enable a commodity to be sold in a distant market

Then again regulatory commissions have approved certain rates in order to put certain cities, jobbers, or industries on alleged equality with their competitors. Of course this kind of rate regulation deprives certain cities and firms of economic advantages due to nearness to markets or raw materials. This kind of rate regulation, which seeks to keep everybody in business, is essentially uneconomic. It causes goods to be hauled by rail when they could be moved more cheaply by boat; it causes goods to be hauled over circuitous routes when direct routes are available; it enables a distant producer of raw materials to outsell a producer nearby; in general, it induces a maximum amount of traffic, while the interests of society require that traffic be kept to a minimum.

Instead of seeking to regulate rates charged by truckers, might it not be better to modify the existing rate structure of the railways?

Is it not pertinent to inquire if the interest shown by railroads in the regulation of truck rates may not be primarily with a view to keeping them high?

—Excerpts from paper by B. E. Hutchinson, vice-president, Chrysler Corp., at Annual Meeting, January, 1933.

Cageless Roller Bearings Develop High Carrying Capacities

By K. L. Herrmann

Engineer, Bantam Ball Bearing Co.

A ROLLER having the same diameter as a corresponding ball and a length equal to the ball diameter has approximately four times the carrying capacity of a ball, according to Mr. Hermann. The data presented on cageless roller bearings are based upon knowledge of the carrying capacity and life of the ball bearing.

The reason for the increased carrying capacity of a roller over that of a ball is due to the distribution of the load over a line of contact rather than at a point of contact. The roller bearing increases the number of such line contacts and therefore further distributes the load to the raceways. By increasing the number of line contacts, the cageless rollers reduce the stress per roller and failure due to fatigue. The fatigue factor is reduced 40 per cent, comparing a cageless with a caged roller.

Formulas are presented which are based on ball-bearing data so that the load-carrying capacity at the various speeds of rotation will give the same life to the cageless roller bearing as would be experienced with the proper ball bearing for the same load and speed.

Hardness of the raceways is discussed and data necessary to apply cageless roller bearings are presented. The methods of assembly are stated.

As to roller specifications and requirements, the rollers are made from wire having an S.A.E. 52100 analysis. The process of manufacture is described and the allowable tolerances are given. Insufficient data are as yet available regarding just how little lubricant is necessary but, thus far, Mr. Hermann says that the installations are running on almost every kind except water.

Car manufacturers using cageless roller bearings for universal-joint trunnions say that lubrication is necessary only after 20,000 miles, or a period of one year. They are lubricating then more as a precautionary measure than as a necessity.

In the discussion, the experience of the manufacturer who pioneered the cageless roller bearing on a universal-joint trunnion is recounted.

WE have as yet been unable to find when cageless roller bearings were first used. A number of examples which we have not been able to verify existed considerably prior to 1897. D. A. Keating, of the Stanley Works, Bridgeport, Conn., designed a very small steel rolling mill in 1897 in which cageless roller bearings were used. The shaft diameter was 2¾ in. The rollers were of 3/16-in. diameter and 7 in. long.

In 1909 Mr. Keating designed and subsequently built seven stands of a 2 in. cold rolling mill in which the roller diameter was 0.120 in. and the length 4 13/16 in., the rollers bearing directly on the roll-neck which was 1¾ in. in diameter. We understand that five of these seven stands are still in operation at Bridgeport.

In a recent case in the Pittsburgh Courts, the construction and details of operation of these needle roller bearings were fully covered and made a matter of record[1].

Another important installation of cageless roller bearings on record is the case of the Franklin Motor Car Co., whose

[1] Details of this installation can be obtained from the District Court of the United States for the Western District of Pennsylvania, No. 2506, dated Jan. 9, 1933.

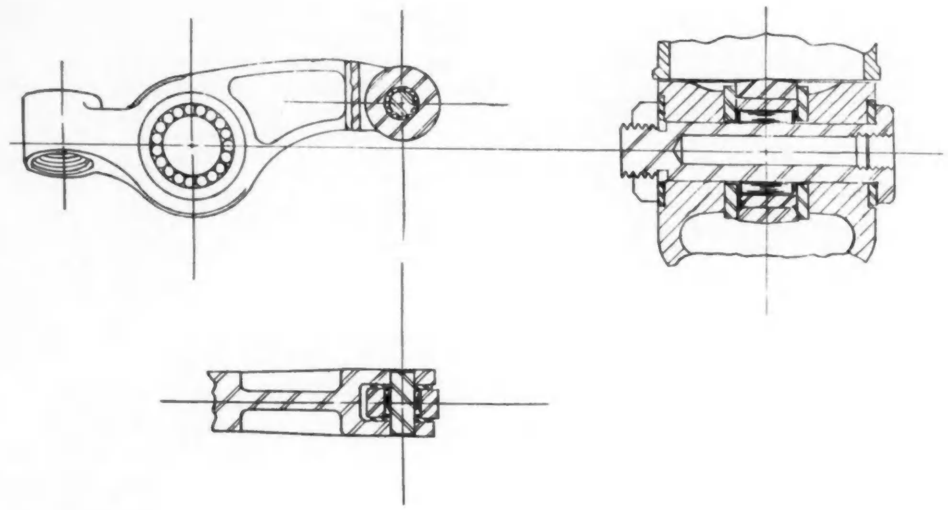


Fig. 1—Valve Rocker-Arm Application

cars in 1914, 1915 and 1916, used cageless roller bearings on the rocker-arms—the rollers being 3/32 in. in diameter and 15/16 in. long—operating on a shaft 0.390 in. in diameter. A typical rocker-arm installation is shown in Fig. 1.

References are also made to the use of cageless roller bearings on express wagons, hand-trucks, bicycles and carriages. A Bantam Ball Bearing Co. predecessor's catalog seems to show that the Bantam Co. manufactured bearings of this type and listed them as early as 1899, at which time the first centerless grinder was made by the Bantam Co. for the purpose of manufacturing these and other rollers.

Adaptability

In these early days cageless rollers of this type were used where low cost, small diameters and high carrying capacities were needed. In many cases it seems that bronze liners were removed because of overheating and that rollers were inserted instead, the roller diameter and length being similar to that of the thickness of the bronze liner and its length. Of course, the metallurgical development did not always make this type of bearing a reliable one, because the rollers usually were made of Stubbs steel or drill rod, which has a tendency to split when hardened and becomes extremely brittle. No doubt, for this reason, only a small number of the heavy-duty installations have come down to us, just as, for similar reasons, the heavy type of roller bearings manufactured prior to 1910 were not entirely satisfactory because of race and roller breakage. For example, one of the early heavy-duty roller-bearing installations were the step bearings at the Niagara Falls powerplant which, prior to 1910, did not stand up in this service. The metallurgical knowledge of the day was very limited and breakage of rollers and races was common because of internal strains and improper material and heat treatment.

With the metallurgical developments of recent years and the successful construction of ball bearings for motor-car service, bearing designers have paid rather small attention to the cageless roller for motor-car work. But in the industrial field, long slim rollers have been used continuously; however, usually with cages. Recently, the development of more perfect wire of the required analysis has made it practicable to manufacture very strong cageless rollers suitable for automotive work which give very high carrying capacities on small-diameter shafts with very small outside diameters of the bearings.

Because many motor-car parts must be manufactured to the required hardness of roller bearings in order that they may wear properly, especially such parts as gears, inner and outer races are not necessary because the rollers can run directly on the parts, thus saving the weight and cost of the inner and of the outer race. Locations where this type of bearing is now in use in regular production are as follows: Transmission pilot bearings (Fig. 2), countershaft bearings, Diesel-engine piston-pins (Fig. 3), Diesel-engine rocker-arms, clutch-finger pivots, various brake cross-shafts, and propeller-shaft trunnion-bearings (Fig. 4), transmission idler gears (Fig. 5), and differential bevel pinions and straddle-mounted, rocker-arm pinion bearings (Fig. 6).

Experiments are now in process in connection with this type of roller for king pins, crankshafts, planetary transmissions and hydraulically sealed water pumps. In the industrial field needle roller bearings are used in machinery, such as printing presses and metal-forming machines, and experiments are being made with this type of bearing on the larger sizes of steel rolling mills. Tentative industrial applications now include pump-shaft mountings, high-speed drill-presses, motion-picture drive-mechanisms, rim rolling mills, welding machines and the like.

Cageless Ball and Roller Bearings Compared

All of our present data are built up from our knowledge of the carrying capacity and life of the ball bearing. It is more or less generally accepted that a roller having the same diameter as a corresponding ball and a length equal to the ball diameter has approximately four times the carrying capacity of a ball. The reason for the increased carrying capacity of a roller over that of a ball is due to the distribution of the load over a line of contact rather than at a point of contact. The cageless roller bearing increases the number of such line contacts and therefore further distributes the load to the raceways.

By increasing the number of line contacts, the cageless rollers reduce the stress per roller and failure due to fatigue.

Table 1—Load-Carrying Capacities of Each Roller in Cageless Roller Bearings Per Inch of Roller Length[a], Lb.

Roller Diameter, In.	Shaft Speed, R. P. M. 50	100	200	300	400	500	800	1,000	1,500	2,000	2,500	3,000	3,500	4,000	5,000
1/16	191	152	120	105	95.5	88.5	76	70	61.5	55.8	51.8	48.8	46.4	44.4	41.2
3/32	286	227	180	157	143.0	133.0	114	105	92.1	84.0	77.7	73.0	69.4	66.4	61.6
1/8	382	303	240	210	191.0	177.0	152	141	123.0	112.0	104.0	97.5	92.6	88.6	82.1
3/16	572	454	360	315	286.0	266.0	227	211	185.0	167.0	156.0	146.0	139.0	133.0	123.0
7/32	668	530	420	368	334.0	310.0	265	246	215.0	195.0	181.0	170.0	162.0	155.0	144.0
1/4	763	605	480	420	382.0	354.0	302	281	246.0	223.0	207.0	195.0	185.0	177.0	164.0

[a] The table is based on the load-carrying capacity of one roller 1 in. in length, and also based on an outer and an inner raceway Rockwell-*C* hardness of 60. The total carrying capacity equals the tabulated load multiplied by the number of rollers, multiplied by the length of the roller in inches, and multiplied by the hardness factor as taken from the chart shown as Fig. 9.

The fatigue factor is reduced 40 per cent, comparing a cageless with a caged roller bearing. In view of the fact that antifriction-bearing failures are largely the result of fatigue of the hardened material, the cageless bearings have the advantage of increased life. The question of fatigue on the raceways is also important. A heavily loaded ball bearing has the same effect on the raceways as a specimen under a Brinell test.

The formulas which are given later are based on ball-bearing data so that the load-carrying capacities at the various speeds of rotation will give the same life to the cageless roller bearing as would be experienced with the proper ball bearing for the same load and speed. The actual derivation of the formula for load-carrying capacity and speed is not a matter of interest; but the use of this formula—which is $R = (N \times L \times d \times 11{,}250)/\sqrt[3]{S}$—*is* of interest. It should be noted, however, that the carrying capacity is a direct function of inner-raceway diameter (that is, "N", the number of rollers and "d", the roller diameter) and the length of the roller so that it then is a direct function of the projected area of the roller pitch-diameter. It should be noted also that the carrying capacity decreases as the cube root of the speed. The diagrammatic sketch, Fig. 7, gives the symbols used in the foregoing formula. Table 1 shows the carrying capacity of rollers of different diameters and 1 in. in length for various speeds in number of revolutions per minute. Table 1 is similar to and functions the same as those in general use for ball bearings. The chart shown in Fig. 8 gives the carrying capacity of the bearing assembly in chart form based on projected area of the roller pitch diameter ($D + d$). This

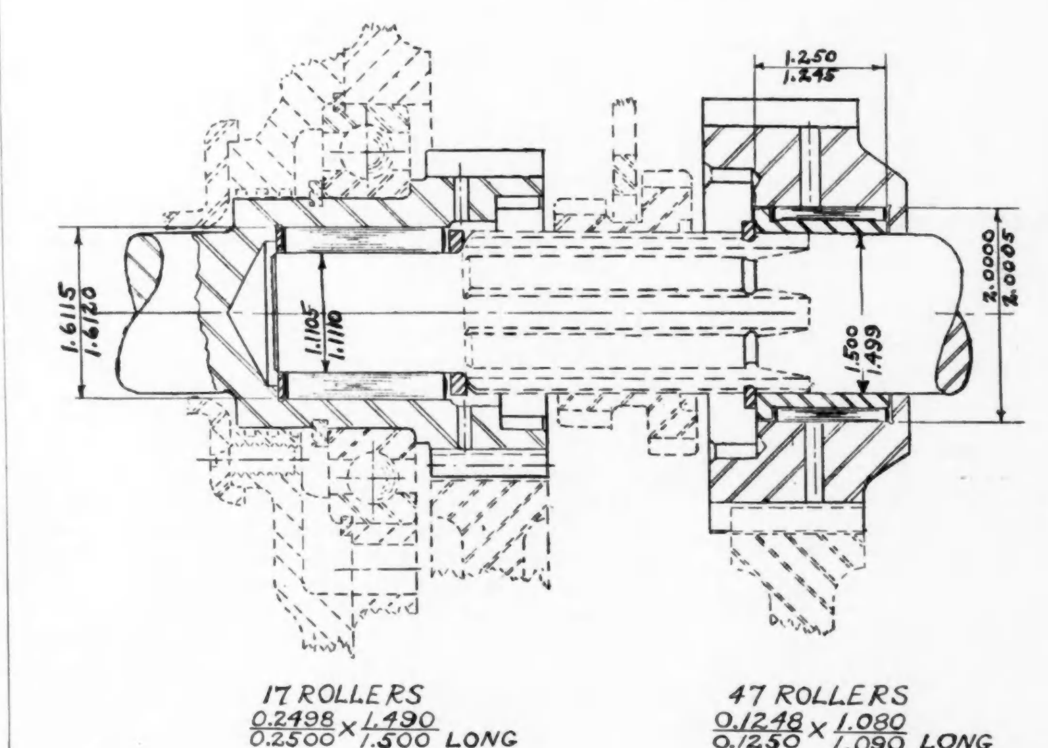


Fig. 2—Transmission Main-Shaft Applications

chart therefore is the same as Table 1 and is based on the formula shown in the sketch, Fig. 7.

The rollers themselves are made from ball-bearing stock. The heat treatment of the cageless rollers of small diameters makes it vital that hardness be obtained without brittleness. To accomplish this, accurate control must be maintained on the analysis of the green wire and on the hardening of machined rollers. The desired Rockwell-*C* hardness of the rollers is 57 to 60. If the decrease in hardness due to tempering is too great, the resultant roller will be brittle and will not withstand impact. To prevent this, the rollers are never drawn more than three points at the Bantam Ball Bearing Co. plant. This leaves a hard surface and a tough core. For example, a 1/16-in. roller actually can be bent before it will fracture. Each diameter of roller requires its own temperature for hardening and tempering. The temperature control on the furnaces and oil bath must be accurate and maintained with a maximum variation of a few degrees. Those who are familiar with the early difficulties experienced with free-wheeling rollers will appreciate that cageless rollers need the same metallurgical attention and control. The carrying capacity of the entire bearing is dependent on the hardness of the raceways. When the hardness of the raceways equals that of the rollers, the capacities as given in Table 1 hold true. When the Rockwell-*C* hardness of either raceway is less than 59 or 60, a load factor must be applied. The load factor for various hardnesses has been worked out empirically and set up in Fig. 9. It should be borne in mind that the load factor to be applied is that for the minimum, whether it occurs on the inner or the outer raceway.

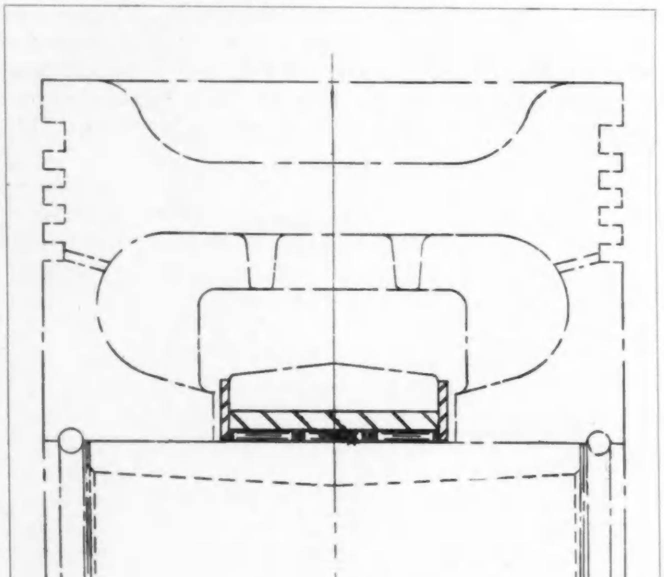


Fig. 3—Piston-Pin Application

Table 2—Values of the Constant *K*
(Arc Subtending Number of Rolls for Full Complement)

No. of Rollers	Value of K	No. of Rollers	Value of K
10	3.236036	51	16.243850
11	3.549509	52	16.561564
12	3.863689	53	16.879250
13	4.178586	54	17.199862
14	4.493978	55	17.517599
15	4.809773	56	17.835304
16	5.125839	57	18.152981
17	5.442316	58	18.470632
18	5.758710	59	18.788252
19	6.075626	60	19.105846
20	6.392635	61	19.427555
21	6.709479	62	19.744845
22	7.026733	63	20.062479
23	7.344090	64	20.380089
24	7.661074	65	20.697669
25	7.978935	66	21.015224
26	8.296583	67	21.336424
27	8.614006	68	21.654949
28	8.931192	69	21.972565
29	9.248982	70	22.290153
30	9.566632	71	22.607719
31	9.884511	72	22.925264
32	10.202520	73	23.242782
33	10.519702	74	23.560273
34	10.838034	75	23.883449
35	11.156268	76	24.201045
36	11.474469	77	24.518626
37	11.791250	78	24.836174
38	12.109316	79	25.153708
39	12.427348	80	25.471218
40	12.745348	31	25.788702
41	13.064441	82	26.106171
42	13.381251	83	26.423612
43	13.699154	84	26.748188
44	14.017024	85	27.065753
45	14.334862	86	27.383306
46	14.660235	87	27.700831
47	14.972682	88	28.018339
48	15.290520	89	28.335836
49	15.608326	90	28.653295
50	15.926103	....	....

To assure that purchasers of the rollers who maintain their own Rockwell testing apparatus keep it accurate and reading correctly through the desired hardness range, the Bantam Ball Bearing Co. supplies *master* hardness blocks that have been checked and rechecked. The company continually checks its own hardness-testing machines against master hardness-blocks from the same run and heat treatment, and the machines are checked by the same outside laboratory. This use of master hardness-blocks prevents the errors which might otherwise creep in due to testing-machine variations.

In connection with the calculating of bearing loads, it was interesting to check up on a Diesel-engine piston-pin appli-

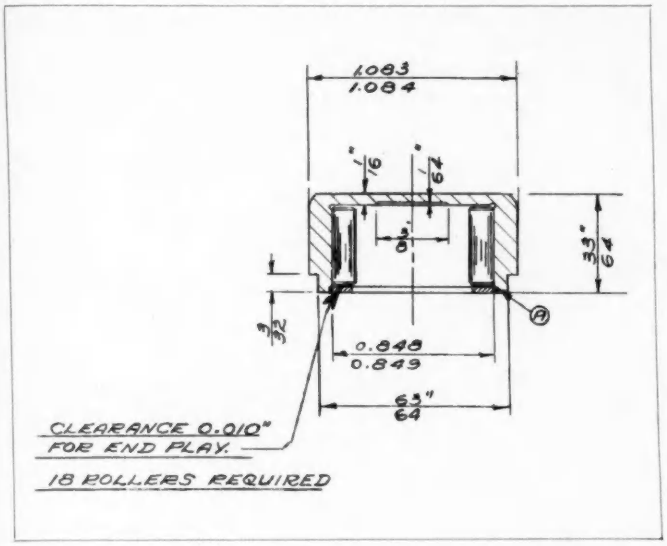


Fig. 4—Universal-Joint Trunnion Cup Assembly

cation made some time ago. According to the size of the rollers and that of the piston pin used, the carrying capacity at 500 r.p.m. would be 37,200 lb. and the pressure would be 4450 lb. per sq. in. of projected area of the pitch diameter. Actually, the bearing functioned at 750 r.p.m. and at a load of 57,500 lb., or a piston-pin pressure of 7300 lb. per sq. in. of projected area. According to a formula advanced by Stellrecht, the life of the bearing would approximate 10 years of normal use; consequently, the rated loads as given by the foregoing formulas are applicable to long-life applications.

We have also recorded a test on the trunnion of a universal joint in which the yoke failed at a load double that indicated for the bearing, yet the rollers and raceways showed no signs of Brinelling or of fatigue or failure of any kind. In fact, it seems as though the bearings will stand more load than the members supported. A statement has been made regarding cageless roller bearings which, without further explanation, would seem ridiculous. It is that "the bearing will stand more load than the shaft." The reasoning back of this is that the shaft as a rule will fail from fatigue fracture caused by deflection before the same fatigue can be set up due to deflection in the raceways or rollers.

Data Necessary To Apply Cageless Roller Bearings

In order that data for cageless roller bearings may be easily calculated we have prepared the tabulation shown in Fig. 7, which covers the necessary data for all but very special applications. The ideal application can be made by calculating from a given roller diameter and establishing the correct diameters of inner and outer raceways. The reason for this method is due to absolute necessity for definite diametral clearance within close tolerances. The first step, therefore, is to establish the approximate number of rollers. This is done from the formula.

$$N \text{ approx.} = \left[(D \text{ approx.} + d) \times 3.1416 \right] / d \qquad (1)$$

Having the approximate number of rollers, we can pick the exact number which is closest to the approximate. The next step is to establish the circumferential clearance. This varies from 0.0001 in. per roller to a maximum of ¼ of the diameter of one roller. The minimum is established from the minimum thickness of lubrication film. The maximum is the reasonable limit for assembling purposes. A greater clearance gives rise to the tendency to overcrowd at assembly. The gap left by the suggested maximum is one which gives the appearance of complete contact without question or counting. Actual operating experience shows that the omission of one roller does not in any way affect the satisfactory functioning of the bearing.

In case it is desirable for assembly reasons, it is possible on some combinations of shaft and roller diameter to have the rollers keystone in the outer raceway. This means that, when the shaft is removed, the rollers drop by gravity and form their own arch and actually lock themselves together. This feature depends entirely on the combination of circumferential clearance, roller diameter and shaft diameter, and no formula or ratios have yet been devised to govern this function. However, where it *can* be obtained, it is a valuable asset in assembling and handling of sub-assemblies.

Having determined the circumferential clearance, we can establish the pitch diameter of the rollers from the formula

$$\text{P.D.} = \left[(Kd \times 3.1416) + \text{C.C.} \right] / 3.1416 \qquad (2)$$

where K is a constant covering the exact arc subtending one roller. Values for K are tabulated in Table 2. By subtracting the roller diameter from the pitch diameter, we obtain the upper limit of the inner raceway or shaft diameter.

The determination of the proper diametral clearance is the next step. This, and its maintenance, is of vital importance to the proper functioning of the complete bearing. The proper clearance is a function of the shaft or inner raceway diameter. For example, on shafts up to 2 in. in diameter, it must be held to from 0.0005 to 0.0015 in.; and on shafts from 4 to 6 in. in diameter, it must be held to from 0.0015 to 0.0025 in. These clearances are based on figuring a high-limit roller and do not allow for press fits or other distortion of the raceways at assembly. Where such distortion is indicated, allowances must be made. Then, by adding the pitch diameter, the roller diameter and the diametral clearance, we have the bore or inside diameter of the outer raceway.

All of the foregoing procedure has determined the mean values and the limits on diametral and circumferential clearance only. Let us consider the tolerances on the mating parts.

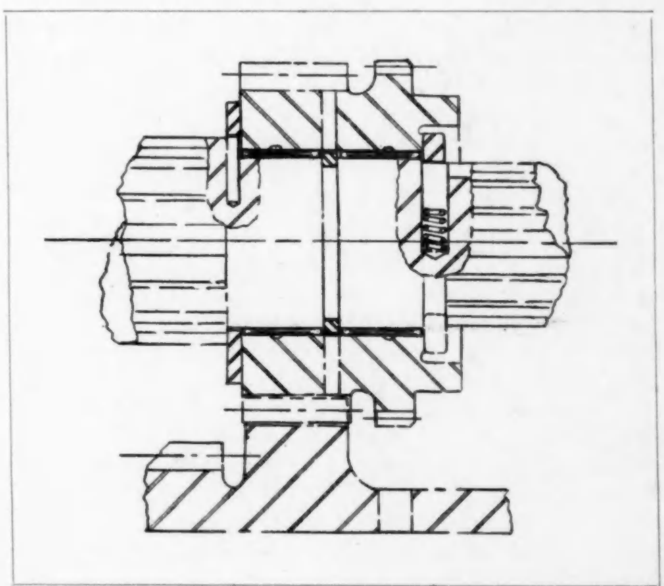


Fig. 5—Transmission Second Speed Main Shaft Gear Adaptation.

On the inner and the outer raceway diameters a tolerance of ±0.00025 in. is necessary for quiet, efficient operation up to a 4-in. diameter of shaft; above this, a tolerance of ±0.0005 in. can in most cases be allowed. The rollers themselves carry a tolerance of +0.0000 and −0.0002 in. on a diameter of ⅛ in. and over. On rollers under ⅛-in. diameter, the tolerance is ±0.0002 in. The taper in the length of the roller is held to 0.0001 in. for all sizes.

The matter of correct bearing length is still questionable. One of the first of this type used was on a bearing 7 in. long, and the rollers ran the full length even though of only a 3/16-in. diameter. Probably, today, that length would be carried on at least four sets of rollers, end to end, with spacers between. Experiments on rollers for piston pins are being made at present on rollers 5 5/16 in. long and ¼ in. in diameter, as well as on three sets of rollers 1 25/32 in. long and 3/16 in. in diameter. Soft rollers 4 in. long and 1/16 in. in diameter have been used in steering gears on the pitman arm shaft. As a rule, however, the individual rollers preferably should have a length somewhere between three and ten times the roller diameter. This would mean groups of rollers, in many cases. Ratios less than 3:1 may tend to cock and would be difficult to handle with hardened rollers. Ratios greater than 10:1 for hardened rollers present manufacturing difficulties and expense. In order that they be held to the required limits for diameter and taper, it would be necessary to work from an abnormally large wire with a resultant waste of material and machining time. Further, it is questionable whether or not a roller having a ratio more than 10:1 distributes the load as uniformly as does a shorter roller. Utilizing the foregoing data, all of the plain bearings can now be replaced with long-life low-cost antifriction bearings.

Methods of Assembly

Sub-assemblies of rollers and shafts can be made up in stockrooms and transferred direct to final assembly in sleeves or on plugs. Where the volume warrants, the sleeves or shafts can be loaded centrifugally, or by gravity. Grease, lacquer or paraffin can be sprayed on the sub-assembly to fix them for severe handling conditions. Commercial applications are now being made in which the reported speed of assembly is too incredible to quote. On the other hand it does prove that, where the volume and the assembly cost warrant, mechanical means can be devised. The servicing of the cageless roller bearing presents no problem. Use them

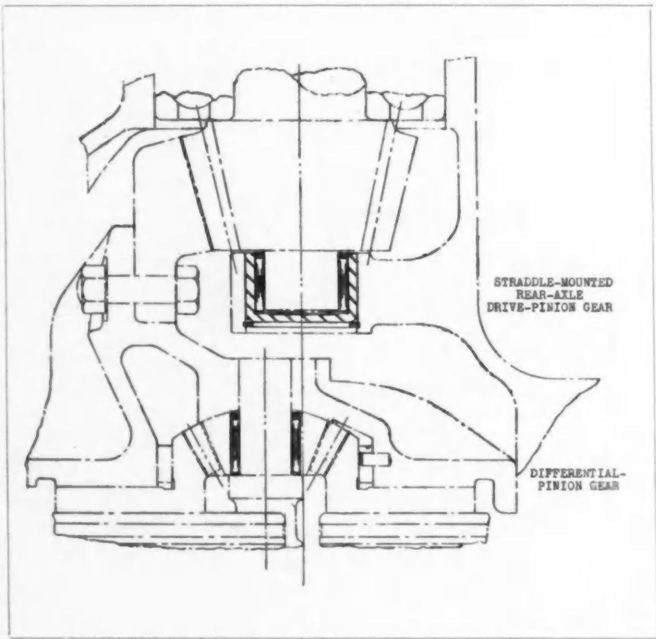


Fig. 6—Rear-Axle Bevel-Gear Applications

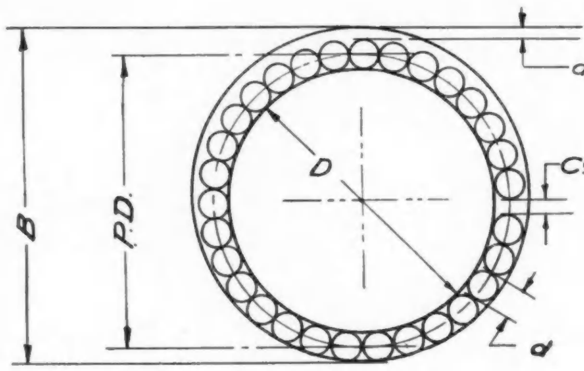


Fig. 7—Cageless Roller Bearing Data

Symbols Used in the Formulas and Calculations

- B = Bore, or inside diameter of the outer raceway, in inches
- $C.C.$ = Circumferential clearance on the pitch diameter, in inches
- D = Diameter, or outside diameter of the inner raceway or shaft, in inches
- d = Diameter, or outside diameter of rollers (nominal size), in inches
- $d.c.$ = Diametral clearance, in inches
- K = Constant taken from Table 2 for the desired value of N
- L = Effective length of roller (less chamfers, radii and the like), in inches
- N = Number of rollers in a full bearing
- π = 3.1416
- $P.D.$ = Actual diameter of the pitch circle of the rollers, including the circumferential clearance
- R = Rated safe load, in pounds
- S = Shaft speed, in number of revolutions per minute

Recommended values for circumferential clearance are: $C.C.$ minimum = 0.0001 in. per roller and $C.C.$ maximum = ¼ of roller diameter.

Recommended Values for Diametral Clearance

Shaft Diameter, In.	Up to 2, In.	2 to 4, In.	4 to 6, In.
$d.c.$ minimum	0.0005	0.0010	0.0015
$d.c.$ maximum	0.0015	0.0020	0.0025

Formulas

$$N \text{ approx.} = [(D \text{ approx.} + d) \times \pi] / d \quad (1)$$

$$P.D. = [(Kd\pi + C.C.) / \pi] \quad (2)$$

$$D = P.D. - d \quad (3)$$

$$B = P.D. + d. + d.c. \quad (4)$$

$$R = (N \times L \times d \times 11{,}250) / \sqrt[3]{S} \quad (5)$$

$$= [(D + d) \times L \times 35{,}340] / \sqrt[3]{S} \quad (6)$$

and one needs no servicing. If care in the selection of size is used, most serviced applications can be made up of the Keystone or self-locking type, preferably in a cup-type outer-raceway, which then becomes a complete bearing unit in itself.

Roller Specifications and Requirements

Thus far, we have outlined the application and uses of the cageless type of roller bearing but have not given much consideration to the rollers themselves. They are made from wire having an S.A.E. 52100 analysis. Upon receipt, the wire is checked for analysis and then cut to length in our automatic press. Then the spherical end is formed. They are then hardened by the batch method in pyrometrically controlled electric furnaces; after this they are quenched in oil. The Rockwell-*C* hardness is then held within the limits of 60 and 62, at this point. They are then tempered in an electrically controlled air furnace and drawn not over three points to a final Rockwell-*C* hardness of 57 to 60. Even though they have this hardness they must still be ductile. To assure this ductility, 1/16-in. diameter and 1/8-in. diameter rollers are given a bend test and they must bend before fracturing. Rollers of 1/8-in. diameter and larger are given an impact test. For example, a 1/8 × 3/4 in. roller must withstand 20 ft.-lb. After heat treating and tests for hardness and ductility, they are rough and finish ground in centerless grinders. They are then checked for size, etched and examined microscopically for grinding checks, burning, and hardness fissures. Next they are lapped in special machines. Following this is a tumbling operation in sawdust to remove lapping compound and dirt, and to clean the roller finally of all foreign material. On 1/8-in. diameter and larger sizes, they are then rechecked to the limits +0.0000 and −0.0002 in.; on 1/8-in. diameter and smaller sizes, to ±0.0002 in. Snap gages, indicators and Johansson blocks are used to maintain this accuracy. When they are checked for size, they are also checked for taper.

A number of different roller ends have been suggested and

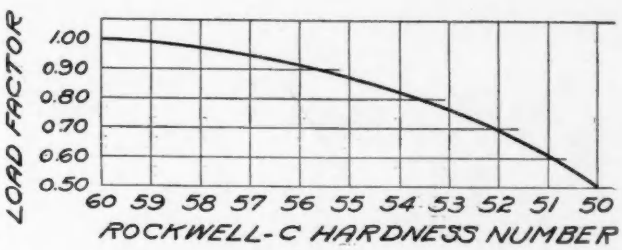


Fig. 9—Hardness—Load Factor Curve

Multiply the rated safe load, *R*, by the load factor taken from the curve for the minimum hardness of the inner or the outer raceway

used (Fig. 10); ends ground square and chamfered, spherically ground ends with the radius equal to the roller radius, spherically ground ends of different radii, and conical ends of various angles and lengths. All of these are expensive; in fact, the ends are worth more than the rest of the roller. The only really satisfactory and practical end is a spherical or ball end of a radius approximately one-half the roller length. This allows the roller to adjust itself with the minimum of disturbance and friction, and shows no tendency to wear the hardened end rings. A system for obtaining this spherical end at an absolutely negligible cost has been devised at the Bantam Ball Bearing Co. plant and has proved commercially satisfactory. The length of the roller to close limits is not essential; in fact, a tolerance of ±0.0075 in. from the mean length is permissible, and more could be given if it were of commercial importance.

The retaining rings on the ends may be any one of several types. They may be hardened shoulders on the raceways, they may be hardened loose rings on the inner and the outer raceways, or they may be pressed on either raceway and have clearance on the other. They may be in the form of snap rings in grooves of either raceway, with clearance on the other. They may be a forged or stamped cup for one end, and have a retaining ring or plate on the other. In this case the cup also functions as the outer raceway, and the whole forms a complete bearing unit. It is essential, however, that the retainers be hard and smooth, preferably ground. The runout tolerance can be such as to allow end-clearance. In the case of split snap rings the split should not exceed 0.010 in. and have commercially square edges without burrs. Grinding or polishing after splitting is necessary. Round wire rings have been used, although flat rings are indicated for roller diameters above 1/8 in. The diametral clearance of end retainers over raceways should be 0.005 to 0.007 in. minimum and 1/4 roller diameter maximum.

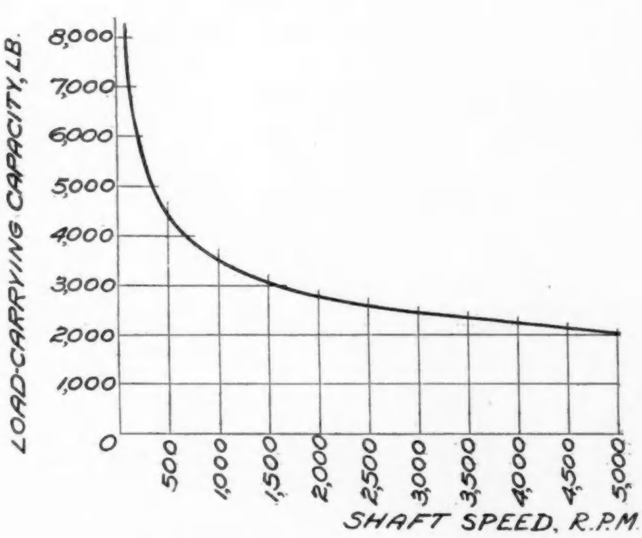


Fig. 8—Rated Load Capacity—Speed Curve

The curve is based on the projected area of the pitch diameter. Multiply the load-carrying capacity by the projected area of the pitch diameter in square inches to obtain the rated load of the bearing

Lubrication

Insufficient data are as yet available as to just how little lubricant is necessary. Thus far, installations are running on almost everything but water. Where heavy greases are employed, such as in the transmission or rear axle, the minimum circumferential clearance should be avoided, although excessive clearances on account of lubricant are not necessary. The centrifugal action is small, and the closeness of contact tends to keep a small amount of lubricant constantly functioning. Any lubrication means applicable to antifriction bearings of other types or to plain bearings will be more than ample.

A test run was made with rollers on the front-axle king-pin. At 25,000 miles on road test, the rollers showed no wear and the original lubricant was still in place. At 50,000 miles

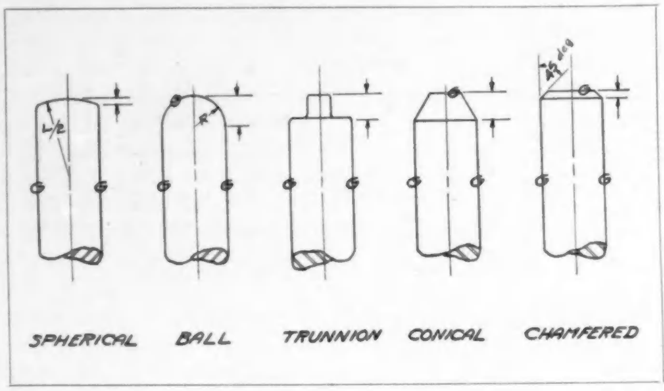


Fig. 10—Types of Roller Ends

the same condition was evident, although the grease holes had been welded up previously. The test has now reached close to 75,000 miles and probably will show an engine or body failure in spite of having the same grease on the king-pin rollers. On this same job it is reported that the change from plain bushings to rollers, without other change in the steering mechanism, reduced the steering-wheel-rim pull 5 lb. This reduction was on the car standing fully loaded, and in this particular instance it amounted to a 25 per cent reduction in static steering effort.

Car manufacturers using cageless roller bearings for universal-joint trunnions are advising us that lubrication is necessary only after 20,000 miles, or a period of one year. They are doing this more as a precautionary measure than as a necessity. Tests being made tend to show that the cageless roller on the trunnion might only need the original lubrication for the life of the car. Even at present, the additional lubricant which would actually get to the trunnions from the spline shafts would undoubtedly be more than sufficient. The small amount of lubricant needed in this location should be welcomed by those car owners who occasionally have to lift their own floor boards.

Discussion

P. E. Miquelon[2]:—We wish to compliment Mr. Herrmann on the excellent paper he has presented. It is timely, and should be helpful in all branches of engineering. First, it broadcasts the fact that manufacturing skill has reached a stage of perfection which permits quantity production of small rollers with the accuracy necessary to their success. Second, it should tend to decrease the timidity of engineers toward the general adoption of the cageless roller bearings, thereby giving us more durable and less troublesome transportation.

As Mr. Herrmann pointed out, the idea of using cageless rollers is very old. The United States Patent Office records letters patent issued to one John G. Tibbets, of New York, in July, 1839, or 94 years ago. This particular application was made on carriage-wheel axles and axle boxes. Since that time a great number of patents issued disclose the use of small cageless rollers, but it seems that all attempts at their practical and commercial application met with failure. At any rate, they made no advancement commensurate with their merit.

[2] Sales engineer, Universal Products Co., Dearborn, Mich.

In our opinion, the success of these small cageless rollers was retarded mainly through the lack of adequate manufacturing facilities. We believe that the development of the centerless grinder had more to do with the success of this type of bearing than did any other one factor. Of course, better knowledge of metallurgy and better designing have made their contribution.

Manufacturing Experience Cited

We believe it might be of interest if we recount the experience of the manufacturer who pioneered the cageless roller bearing on a universal-joint trunnion. The Universal Products Co., Inc., Dearborn, Mich., began tinkering with cageless rollers about six years ago. Even at that time we were convinced of the value of this type of antifriction bearing for universal joints, but we had not found a satisfactory method for their application. During the ensuing years the problem came up periodically, without being solved until the summer of 1930. At that time we succeeded in designing a cageless roller bearing that had all the features we had been searching for; namely, it

(1) Was a self-contained unit
(2) Had a closed outer end to prevent the loss of lubricant through centrifugal force
(3) Made the exclusion of dirt simple and positive
(4) Was easy to service
(5) Had a low cost

Since that bearing unit was designed, and we believe the Universal Products Co. was the first to make a self-contained bearing with cageless unguided rollers, all troubles with universal joints have disappeared. Experimentally, laboratory test after laboratory test has been made for hundreds of hours without a semblance of a failure. Propeller shafts equipped with these bearings have been driven 50,000 miles on 24-hr.-test cars, and they have shown absolutely no wear or loss of lubricant.

Since the Fall of 1930, we have delivered among nine passenger-car manufacturers about 140,000 propeller shafts, the universal joints of which had cageless rollers. This means that a total of about 600,000 bearing units are in the field doing duty.

During all the testing we have made, on our own equipment as well as outside equipment, and from all the universal joints we sent out into the field during a period of three years, we have had only two failures. One was on an experimental car and was caused by angular interference. The type of bearing used had nothing to do with this break. The other propeller shaft was returned from the field after 6000 miles of usage. Two of its trunnion pins, on which the small rollers bear, had worn prematurely because they had not been hardened properly at the time of fabrication. So, we are forced to say that through a period of three years, and under all kinds of tests imaginable, these small rollers have performed 100 per cent.

At the outset of our production of these small bearings, we had great difficulty in building up our courage sufficiently to say out loud, what we knew very well to be a fact; this is that a universal joint fitted with cageless roller bearings would "last during the life of the car." However, our experience since then, both in the servicing and in the life of these small cageless rollers, reads right on top of Mr. Herrmann's statement: "Use them and one needs no servicing."

Temperature Effect on Determination of Gum in Gasoline

By O. C. Bridgeman and J. C. Molitor

THE paper[1] constitutes the fourth progress report to the Society on the investigation at the Bureau of Standards of the gumming characteristics of gasolines.

Previous work has shown that the relative gum contents of a series of gasolines are the same, regardless of the volume evaporated. In the present paper, experimental data are given which indicate the effect of variations in bath temperature on the determination of gum content. These data show that the relative gum contents of a series of gasolines are the same, regardless of the bath temperature.

Accordingly, it is concluded that any convenient volume of gasoline can be evaporated at any convenient temperature with equal significance. Preference is expressed for the evaporation at a temperature of 200 deg. cent. (392 deg. fahr.), due to the rapidity with which a determination of gum content can be made.

ENGINE trouble resulting from deposition of gum on inlet valves or in the intake manifold has not been very extensive, owing largely to the efforts of the petroleum industry in controlling the gum contents of gasolines. Any trouble which has occurred can be attributed almost entirely to the lack of definite information on permissible gum contents and to the lack of a satisfactory method for the determination of gum content. The general trend toward increased antiknock value of gasolines by more intensive cracking enhances the seriousness of the gum problem and makes it imperative that a satisfactory test method be established and permissible gum contents be determined as soon as possible.

To obtain the desired information before the problem should become acute, an investigation of the gumming characteristics of gasolines was started at the Bureau of Standards somewhat over two years ago under the auspices of the Army Air Corps and, within the last year, the supervision of the work was taken over by the Cooperative Fuel Research Steering Committee. Considerable information has been obtained

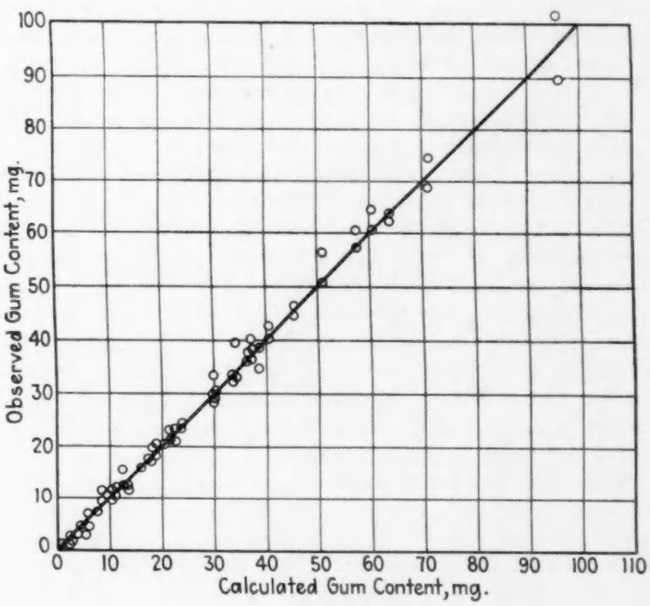


Fig. 1—Air-Jet Volume Series

The agreement between the observed weights of gum, obtained on evaporation of various volumes of a number of gasolines, and values computed from equation (1) using the appropriate value of b for each gasoline, is shown.

[This paper was presented at the 1932 Semi-Annual Meeting of the Society.]

Mr. Bridgeman is chief, lubrication and liquid fuels section, Bureau of Standards, City of Washington.

Mr. Molitor is research associate, Bureau of Standards, City of Washington.

[1] Publication approved by the Director of the Bureau of Standards of the United States Department of Commerce.

Table 1—Gum Contents of Gasoline by the Liquid-Bath Air-Jet Method

Bath Liquid Employed	Gasoline No.	Gum Content per 50-Ml. Portion, Mg. 15 min.	Drying	20 hr.	Drying
Tetralin	1	3.3	3.5	3.0	3.1
	2	5.6	4.9	5.8	4.9
	3	14.3	15.7	14.6	15.8
	4	17.1	16.7	17.9	17.1
	5	22.0	21.1	22.2	21.5
	6	31.4	32.8	31.3	33.0
Amyl Acetate	1	5.8	6.1	3.7	4.1
	2	9.1	9.0	7.4	6.6
	3	17.7	19.7	16.7	18.2
	4	31.0	29.4	26.9	25.3
	5	32.0	32.9	30.2	31.8
	6	38.3	38.3	35.3	36.9
Water	1	11.9	12.0	6.3	5.9
	2	27.6	27.1	11.8	10.4
	3	28.7	32.1	20.2	21.4
	4	63.6	62.9	35.8	36.4
	5	55.2	56.3	36.0	36.8
	6	83.6	80.0	48.9	45.9
Methyl Alcohol	1	19.8	18.9	7.8	6.4
	2	41.5	40.6	13.3	13.3
	3	58.4	57.9	29.4	27.9
	4	97.8	99.1	44.7	43.4
	5	108.1	113.7	53.9	59.9
	6	161.2	161.4	68.6	72.6

to date, and the present paper constitutes the fourth progress report to the Society on the investigation of this problem.

In common with other fuel problems, this one involves not only fuel characteristics but also engine operating conditions and engine design. In a given engine operated under the same conditions, the amounts of gum deposited from a series of gasolines will be in the same order as their gum contents. With a gasoline of given gum content, the amount deposited may vary considerably from car to car and even in the same car under different operating conditions. If no evaporation takes place in the intake system, no gum will be deposited. If there is complete evaporation in the intake system, much of the gum may be carried into the cylinders in the form of fine particles. Between these extremes there is a wide range covering the usual conditions in the intake system, in which the amount of gum deposited will depend upon the percentage of the fuel which evaporates before reaching the cylinders, the relative amount of liquid which evaporates in the air stream and on the manifold walls or valve stems, the degree of atomization, the turbulence in the manifold and the temperature in the intake system.

Plans are now being made for an extensive investigation of permissible gum contents; but, obviously, before such an investigation can be seriously undertaken, it is necessary to have a satisfactory method for the determination of gum content. However, before a method for the determination of gum content can be satisfactory, it must not only be reproducible but it must also be significant as regards gum deposition in the engine. In a dilemma of this nature, it is necessary to determine the primary variables from the fuel standpoint which affect gum deposition in the manifold and then to evaluate the effect of these variables on the results obtained by a laboratory method simulating manifold conditions. This was the procedure employed in the present investigation.

The outstanding characteristic of evaporation in the manifold is that the gasoline evaporates in a current of air, and the primary variables from the fuel standpoint appear to be time of evaporation and temperature of evaporation. The laboratory work has shown that the relative gum contents of a series of gasolines are independent of the time of evaporation and of the bath temperature at which evaporation occurs under an air jet. Accordingly, any convenient and reproducible air-jet method should give results which are in the same order as the amounts of gum deposited from these gasolines in a given engine. As already pointed out, variations in the amounts of gum deposited in different engines are due to design factors and hence do not enter into a study of methods for determining gum contents.

Outline of Experimental Work

All of the data on gum contents reported herein were obtained by evaporation of gasolines from glass dishes, using an air jet. The rate of air flow employed was 700 to 800 ml. per sec., which was as high as could safely be used without blowing liquid out of the dish. Three variations of the air-jet method were investigated in that gasolines were evaporated under an air jet (*a*) on the steam bath, (*b*) in an air oven at various temperatures, and (*c*) in liquid baths at various temperatures. These variations of the air-jet method will be referred to in this paper as the steam-bath, air-oven, and liquid-bath methods, respectively. With each method, the effect of varying the volume evaporated was investigated, while with the two latter methods the effect of changes in bath temperature also was studied.

In the case of the steam-bath evaporations, the air passing

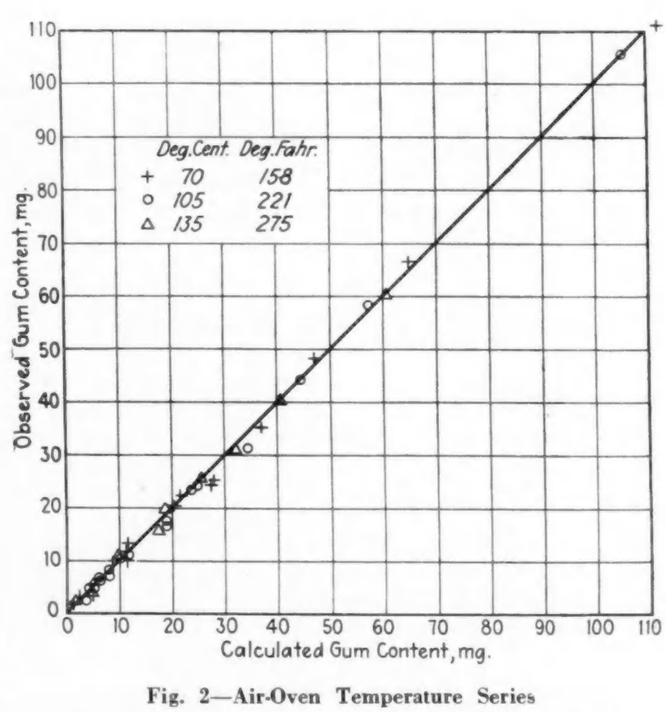


Fig. 2—Air-Oven Temperature Series

The values found for the three volumes of each gasoline evaporated were in agreement with equation (1) and the agreement between the observed values and those calculated from the equation is shown.

through the jet was only slightly above room temperature. In the other two methods, the air was preheated approximately to the bath temperature. In all cases, dry air was employed. For evaporation on the steam bath and in the special air oven, flat-bottomed pyrex evaporating dishes, about 80 mm. in diameter and 45 mm. in depth, were used. For evaporation in the liquid bath, 100-ml. pyrex beakers without lips, about 50 mm. in diameter and 80 mm. in depth, were employed. The preliminary treatment of the evaporating dishes and the beakers was the same in all cases. After careful cleaning, they were heated in an air oven at 105 deg. cent. (221 deg. fahr.) for at least 2 hr., removed and allowed to stand in a desiccator containing calcium chloride for 20 min., and finally weighed to 0.1 mg. on a balance inclosed in a case containing calcium chloride.

The treatment of the dishes after evaporation of the gasoline varied in the three methods. In the case of the steam-bath evaporations, after apparent dryness was reached, the dishes were heated in an air oven at 105 deg. cent. for 20 hr. before weighing. In the case of the special air-oven evaporations, the dishes were left under the heated air jet for 2 hr., after which they were placed in an air oven at 105 deg. cent. for 20 hr. before weighing. With the liquid-bath evaporations, the dishes were left in place for 15 min. after apparent dryness was reached. They were then cooled in the desiccator and weighed, after which they were heated in the air oven at 105 deg. cent. for 20 hr., cooled and weighed again.

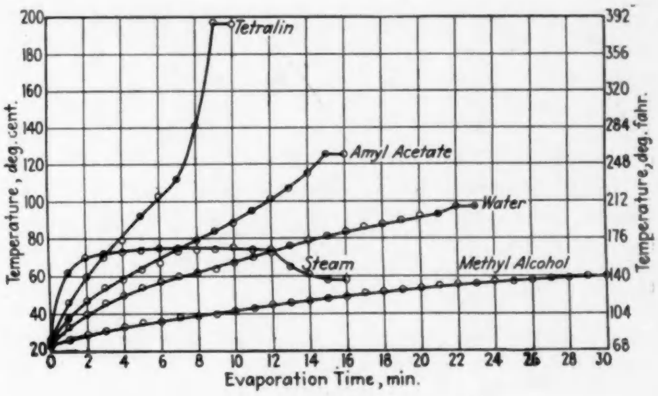


Fig. 3—Typical Time-Temperature Curves

A curve for the gasoline temperature during evaporation under an air jet on the steam bath is also included, for comparison.

A description of the apparatus used for the air-oven air-

Table 2—Gum-Content Values in Liquid-Bath-Temperature Series

Bath Liquid Employed	Gasoline No.	Gum Content per 50-Ml. Portion, Mg. Observed		Calculated	Differences, Mg. Observed	Calculated	Average Values, Ratio
Tetralin	1	3.0	3.1	3.4	−0.4	−0.3	0.11
	2	5.8	4.9	5.8	0.0	0.9	0.19
	3	14.6	15.8	13.8	0.8	2.0	0.45
	4	17.9	17.1	20.5	−2.6	−3.4	0.67
	5	22.2	21.5	24.5	−2.3	−3.0	0.80
	6	31.3	33.0	30.6	0.7	2.4	1.00
Amyl Acetate	1	3.7	4.1	4.1	−0.4	0.0	....
	2	7.4	6.6	7.0	0.4	−0.4	....
	3	16.7	18.2	16.6	0.1	1.4	....
	4	26.9	25.3	24.7	2.2	0.6	....
	5	30.2	31.8	29.5	0.7	2.3	....
	6	35.5	36.9	36.9	−1.4	0.0	....
Water	1	6.3	5.9	5.4	0.9	0.5	....
	2	11.8	10.4	9.3	2.5	1.1	....
	3	20.2	21.4	22.0	−1.8	−0.6	....
	4	35.8	36.4	32.8	3.0	3.6	....
	5	36.0	36.8	39.1	−3.1	−2.3	....
	6	48.9	45.9	48.9	0.0	−3.0	....
Methyl Alcohol	1	7.8	6.4	7.5	0.3	−1.1	....
	2	13.3	13.3	13.0	0.3	0.3	....
	3	29.4	27.9	30.9	−1.5	−3.0	....
	4	44.7	43.4	46.0	−1.3	−2.6	....
	5	53.9	59.9	55.0	−1.1	4.9	....
	6	68.6	72.6	68.6	0.0	4.0	....
Air Jet	1	6.5	6.9	6.7	−0.2	0.2	....
	2	9.9	11.2	10.6	−0.7	0.6	....
	3	22.7	25.4	24.0	−1.3	1.4	....
	4	36.8	38.4	37.6	−0.8	0.8	....
	5	46.5	47.7	47.1	−0.6	0.6	....
	6	53.6	55.7	54.6	−1.0	1.1	....

Average Difference = 1.3 mg.

Table 3—Gum-Content Values

Fuel No.	Volume Evaporated, Ml.	Gum Content per 50-Ml. Portion, Mg. Observed		Gum Content per 50-Ml. Portion, Mg. Calculated	Differences, Mg. Observed	Differences, Mg. Calculated	Average Values, Ratio
Tetralin Bath							
13	80	81.0	72.5	80.0	+1.0	−7.5	1.00
12		61.1	53.0	58.4	+2.7	−5.4	0.73
11		49.7	48.9	46.4	+3.3	+2.5	0.58
10		33.8	35.5	31.2	+2.6	+4.3	0.39
9		25.6	23.5	25.6	0.0	−2.1	0.32
7		21.7	22.6	20.0	+1.7	+2.6	0.25
13	60	55.8	57.0	56.5	−0.7	+0.5	...
12		38.8	38.4	41.3	−2.5	−2.9	...
11		37.0	38.8	32.8	+4.2	+6.0	...
10		21.7	22.5	22.0	−0.3	+0.5	...
9		16.1	17.5	18.1	−2.0	−0.6	...
7		13.4	13.1	14.1	−0.7	−1.0	...
13	40	23.5	23.2	26.3	−2.8	−3.1	...
12		22.2	19.2	19.2	+3.0	0.0	...
11		17.0	17.9	15.2	+1.8	+2.7	...
10		10.5	12.4	10.3	+0.2	+1.1	...
9		8.7	8.6	8.4	+0.3	+0.2	...
7		6.5	6.8	6.5	0.0	+0.3	...
13	20	10.2	11.2	11.4	−1.2	−0.2	...
12		8.7	8.3	8.3	+0.4	0.0	...
11		7.4	6.4	6.6	+0.8	−0.2	...
10		4.4	4.9	4.6	−0.2	+0.3	...
9		2.8	2.7	3.7	−0.9	−1.0	...
7		2.8	1.9	2.8	0.0	−0.9	...
Water Bath							
13	80	120.6	119.2	119.1	+1.5	+0.1	1.00
12		87.4	87.0	87.2	+0.2	−0.2	0.73
11		64.4	61.7	69.3	−4.9	−7.6	0.58
10		44.3	41.5	46.6	−2.3	−5.1	0.39
9		40.6	43.8	38.2	+2.4	+5.6	0.32
7		25.7	27.8	29.8	−4.1	−2.0	0.25
13	60	84.8	88.2	85.1	−0.3	+3.1	...
12		60.3	60.2	62.1	−1.8	−1.9	...
11		42.7	46.1	49.4	−6.7	−3.3	...
10		31.7	32.6	33.2	−1.5	−0.6	...
9		29.5	25.1	27.3	+2.2	−2.2	...
7		18.7	19.0	21.3	−2.6	−1.3	...
13	40	45.9	48.9	48.9	−3.0	0.0	...
12		40.1	40.6	35.7	+4.4	+4.9	...
11		25.8	25.1	28.4	−2.6	−3.3	...
10		18.7	17.1	19.1	−0.4	−2.0	...
9		15.7	16.6	15.7	0.0	+0.9	...
7		12.1	11.4	12.2	−0.1	−0.8	...
13	20	21.2	19.6	20.4	+0.8	−0.8	...
12		15.5	15.8	14.9	+0.6	+0.9	...
11		11.9	11.8	11.8	+0.1	0.0	...
10		7.5	7.0	8.0	−0.5	−1.0	...
9		6.5	5.4	6.5	0.0	−1.1	...
7		5.5	5.8	5.1	+0.4	+0.7	...

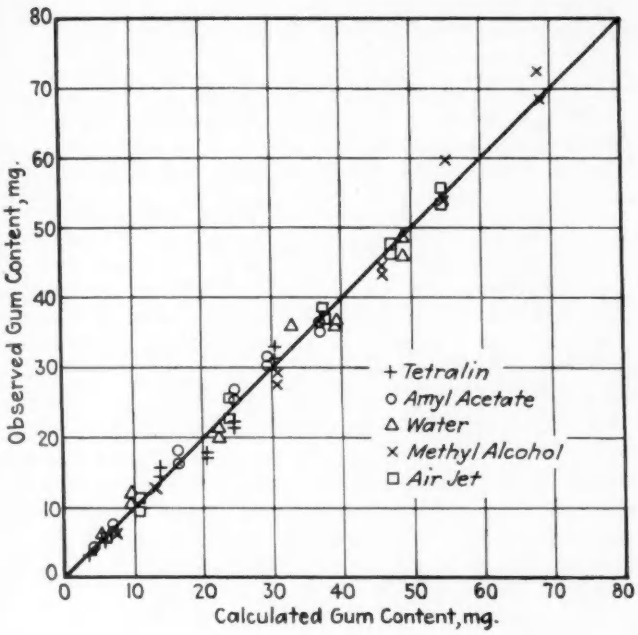


Fig. 4—Comparison between Observed and Calculated Values of Gum Content for the Liquid-Bath Temperature Series

jet determinations has previously been given[2]. The apparatus used for the liquid-bath determinations was kindly made available by the General Motors Research Laboratories[3]. It consisted essentially of an inclosed cylindrical container in the top of which was inserted a well just large enough to accommodate the glass beaker with a clearance of about 2 mm. The container was filled with various liquids which were heated to their boiling points by means of a hot-plate electric-heater. The air flowing through the jet was preheated by passing through a metal coil immersed in the boiling liquid.

Steam-Bath Results

In a previous paper[4], a large volume of experimental data was presented showing indirectly the effect of time of evaporation on the measured gum contents of gasolines. Since it is difficult to control this factor directly, the procedure adopted was to evaporate various volumes—ranging from 10 to 90 ml.—of each gasoline on the steam bath. Variations in the weight of residue, computed back to 100 ml. of gasoline, were then indicative of the effect of evaporation time on the measured gum content. It was found that the data on each gasoline could be represented within experimental error by an equation of the type

$$W = b\,(100 + V) \qquad (1)$$

where W is the weight of gum computed on a basis of 100 ml.; V is the volume evaporated, in milliliters; and b is a constant for each gasoline. The agreement between the observed weights of gum, obtained on evaporation of various volumes of a number of gasolines, and values computed from Equation (1) using the appropriate value of b for each gasoline, is shown in Fig. 1.

It is obvious from Equation (1) that the relative gum contents of any two gasolines, obtained by evaporating equal volumes, are independent of the particular volume evaporated since $100 + V$ is the same in the two cases. Accordingly, changes in time of evaporation brought about by changes in the volume evaporated compensate in such a way that the relative gum contents of the two gasolines are unchanged. This conclusion holds regardless of differences in the time of evaporation between the two gasolines, for a given volume evaporated.

Air-Oven Results

The experiments on volume evaporated, and hence on time of evaporation, referred to in the foregoing section, were conducted at one temperature; namely, on the steam bath. Use of an air oven permits a study of the effect of air temperature, as well as of volume evaporated. In a previous paper[5], data were presented on the weights of residue obtained on evaporation of three volumes of each of six different gasolines under the air jet in an air oven maintained at the three temperatures, 70, 105 and 135 deg. cent. (158, 221 and 275 deg. fahr.). The values found for the three volumes of each gasoline evaporated were in agreement with Equation (1), and the agreement between the observed values and those computed from the equation is shown in Fig. 2. Air-oven temperature was found to have only a slight effect on the measured gum content. The relative gum contents of the six gasolines were the same within experimental error, regardless of the temperature or the volume which was evaporated. These data are of particular interest since the conditions of evaporation in the manifold vary largely as the result of changes in the temperature of the air passing through the manifold, caused either by hot spots or by preheating.

Liquid-Bath Results

The small influence of air-oven temperature on the magnitude of the measured gum contents found in the air-oven

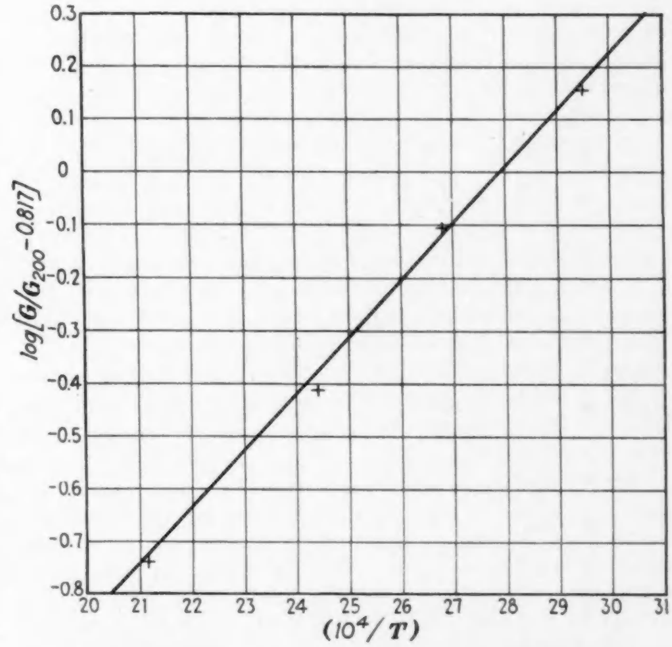


Fig. 5—Indication of the Precision of Equation (2)

The straight line represents the equation and the plotted points are the smoothed values from the fifth column of Table 2.

[2] See S.A.E. Transactions, 1931, vol. 26, p. 484.
[3] See Proceedings of the American Society for Testing Materials, vol. 32, 1932, part 1, p. 412, for a description of this apparatus.
[4] See S.A.E. Transactions, 1931, vol. 26, p. 484.
[5] See S.A.E. Transactions, 1931, vol. 26 p. 484.

Table 4—Comparison of Values by Steam-Bath and Tetralin-Bath Air-Jet Methods

Gum Content per 50-Ml. Portion, Mg.

Fuel No.	Cold-Air Jet Steam Bath		Hot-Air Jet Tetralin Bath	
1	6.9	6.5	3.3	3.5
2	9.9	11.2	5.6	4.9
3	22.7	25.4	14.3	15.7
4	36.8	38.4	17.1	16.7
5	46.5	47.7	22.0	21.1
6	53.6	55.7	31.4	32.8
7	19.6	21.3	10.6[a]	
9	25.0	25.3	12.5[a]	
10	32.2	32.5	17.1[a]	
11	41.9	43.6	25.6[a]	
12	56.3	58.5	28.3[a]	
13	76.6	78.9	39.0[a]	
14	78.0	82.7	32.3	32.6
15	64.5	71.8	25.2	26.1
16	36.8	38.1	16.3	17.5
17	35.4	35.5	16.8	16.7
18	29.4	30.2	11.3	12.3
19	41.4	47.9	25.6	22.5
20	43.2	39.3	19.7	20.1
21	25.1	24.2	13.0	11.5
22	14.1	14.6	7.1	5.5
23	19.9	19.9	9.8	11.0
24	9.4	10.2	5.8	5.1
25	75.1	78.2	34.0	34.8

[a]Calculated from equation $\frac{W}{V} = b(100 + V)$

series was attributed to the fact that, owing to the low heat-capacity of air and the high latent-heat of evaporation of gasoline, the actual gasoline temperatures were about the same at the three oven temperatures. Accordingly, a second series of experiments was undertaken in which the gasolines were heated by liquids boiling at various temperatures. Four different bath liquids were employed; namely tetralin, amyl acetate, water and methyl alcohol, and the average measured bath temperatures were 200, 137, 100 and 66 deg. cent. (392, 279, 212, and 151 deg. fahr.), with occasional fluctuations of plus or minus 2 deg. cent. (3.6 deg. fahr.).

Preliminary to determining gum contents by the liquid-bath method, measurements were made of the change in temperature of several gasolines during the course of evaporation under an air jet at each of the above bath temperatures. For this purpose, a thermocouple was inserted in the gasoline. Typical time-temperature curves for one gasoline are shown in Fig. 3 where, for comparison, a curve for the gasoline temperature during evaporation under an air jet on the steam bath is also included.

During the steam-bath evaporation the temperature rises much more rapidly than during evaporation with the liquid baths, since the rate of heat transfer to the gasoline is more rapid in the former case. The curve for the steam-bath evaporation is peculiar in that the temperature drops toward the end of the evaporation, owing presumably to the fact that the air flowing through the jet is approximately at room temperature during the steam-bath evaporation, whereas the air is preheated to bath temperature in the other four cases. The approximate times of evaporation to apparent dryness in the case of the gasoline used for obtaining the data shown in Fig. 3 were: tetralin, 10 min.; amyl acetate, 15 min.; water, 22 min.; methyl alcohol, 75 min.; and steam, 16 min. The time of evaporation at various bath temperatures varies somewhat with different gasolines.

The first series of determinations by the liquid-bath method consisted in evaporating 50-ml. portions of six gasolines at each of the four bath temperatures. The results are given in Table 1. It is seen that additional drying in the air oven at 105 deg. cent. (221 deg. fahr.) for 20 hr. does not change the weight of the gum appreciably when tetralin is used as a bath liquid, but does produce considerable change after evaporation at the three lower bath temperatures. The actual gum contents of the gasolines decrease considerably with increase in bath temperature, but the relative gum contents are independent of bath temperature. In establishing this conclusion the relative gum contents at each bath temperature were obtained, the gum content of sample No. 6 being taken as unity. A comparison of the relative gum contents, thus obtained, indicated that they were independent of bath temperature within close limits. The average values are shown in the last column of Table 2, designated as ratios.

For each bath temperature, the ratios were multiplied by a factor to give the calculated values shown in the fifth col-

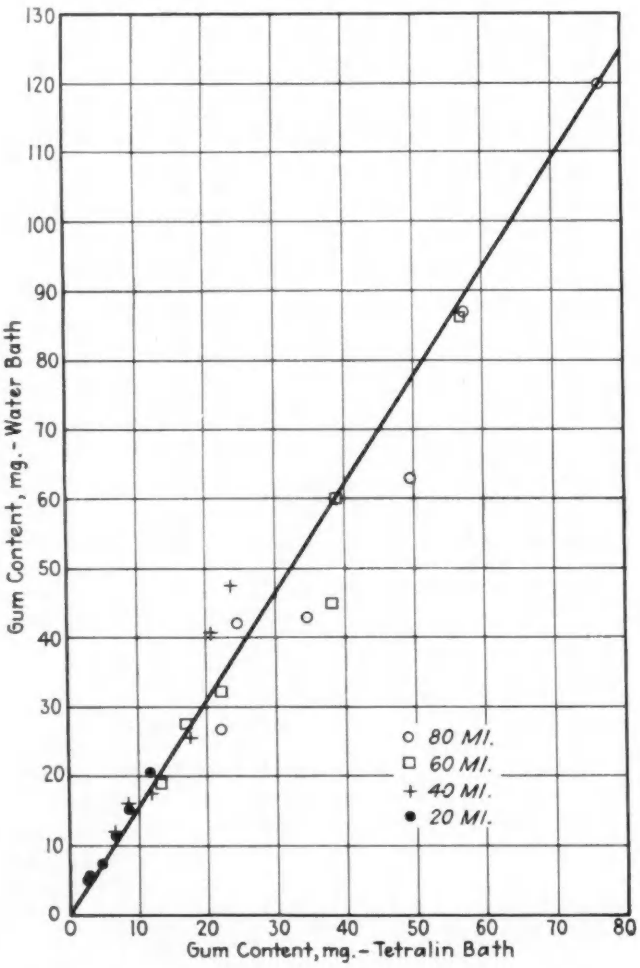


Fig. 6—Curve Showing That the Relative Gum Contents Are Independent of both Temperature and Volume Evaporated

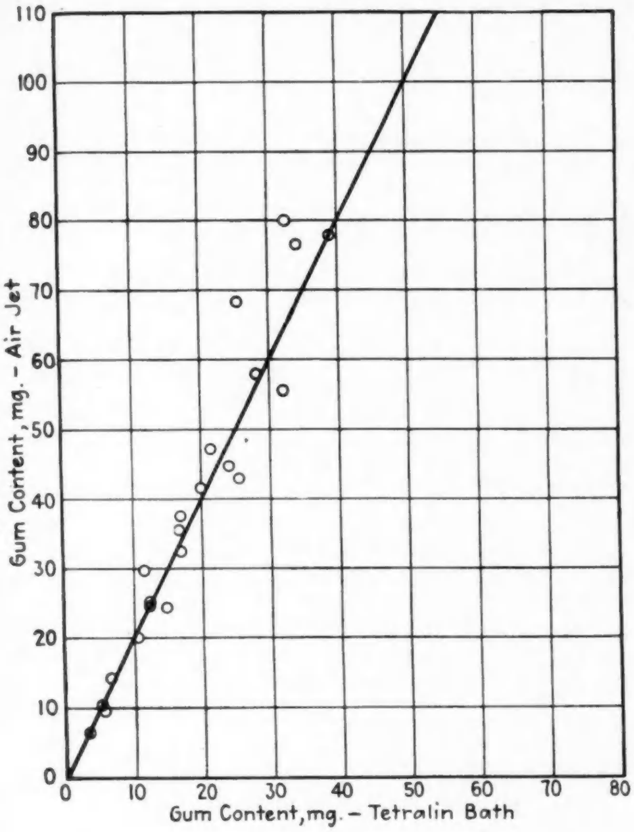


Fig. 7—Curve Showing That, on the Average, Gum-Content Values when Using a Tetralin Bath Are 50 Per Cent of Those Obtained by the Steam-Bath Method

umn. The choice of the factor used was such as to make the average deviation between observed and computed values a minimum, which is equivalent to assuming that all of the measured values are subject to equal errors. For comparison, data for the same gasolines obtained by the steam-bath method are also included, and the same ratios hold for these data as for the values at the various liquid-bath temperatures. The differences between the observed and computed values are shown in the sixth and seventh columns of Table 2, the grand average deviation being 1.3 mg. A plot of the observed and computed values is shown in Fig. 4.

The magnitude of the change in gum content with bath temperature is of particular interest. Analysis of the data indicated that the following equation accurately reproduced the experimental results.

$$\log [(G/G_{200}) - 0.817] = -3 + (1075/T) \quad (2)$$

where G is the gum content at any liquid-bath temperature, G_{200} is the gum content using a tetralin bath, and T is the temperature of the bath liquid in absolute degrees centigrade. The precision of Equation (2) is indicated in Fig. 5, where the straight line represents the equation and the plotted points are the smoothed values from the fifth column of Table 2. It should be emphasized that Equation (2) holds only for the type of liquid-bath apparatus used in the present work and that, for other types of apparatus, different numerical values would have to be employed for the constants in the equation.

In a second series of determinations with the liquid-bath apparatus data were obtained on six gasolines, evaporating four volumes in each case and using tetralin and water as bath liquids. The residues were dried for an additional 15 min. at both bath temperatures; but, in the case where water was used as a bath liquid, the residues were dried further for 20 hr. in an air oven at 105 deg. cent. (221 deg. fahr.) before weighing. The data are shown in Table 3 where the calculated values were obtained in the same manner as that described for Table 2. The relative gum contents are seen to be independent of both temperature and volume evaporated. This is further illustrated in Fig. 6, where the line through the plotted points is computed from Equation (2), which indicates that

$$G_{200} = 0.64\, G_{100} \quad (3)$$

where G_{200} and G_{100} represent the measured gum contents using tetralin and water respectively as the bath liquids.

As a further check on the conclusion that the relative gum contents were independent of bath temperature, data were obtained on evaporation of 50-ml. portions of 12 additional gasolines by the steam-bath method and the liquid-bath method, using tetralin as a bath liquid. These data are given in Table 4 together with values on six gasolines previously given in Table 2 and steam-bath values on the six gasolines used in the comparison of water and tetralin as bath liquids. The tetralin values for evaporation of 50 ml. in this latter case were interpolated between the 40 and 60-ml. values. All of the comparative results by these two methods are shown in Fig. 7, where it is seen that, on the average, values using a tetralin bath are 50 per cent of those obtained by the steam-bath method. Referring to Equation (2), this ratio indicates that the steam-bath values are equivalent to those which would have been obtained in the liquid-bath apparatus at a temperature of 77 deg. cent. (171 deg. fahr.).

Summary

In the investigations which have been conducted at the Bureau leading toward the establishment of a method for determining gum contents of gasolines, two important conclusions have been reached. In the first place, the relative gum contents of any two gasolines are the same, regardless of the particular volume evaporated, as long as the same volumes are evaporated at the same bath temperature. In the second place, the relative gum contents of any two gasolines are the same, regardless of the particular bath temperature, as long as the same bath temperature is employed in the two cases and the same volume evaporated. Further, the relative gum contents are the same when different volumes are evaporated at different bath temperatures, the same volume and temperature being used in any one series of determinations.

Accordingly, an air-jet method can be chosen in which any convenient volume can be evaporated at any convenient bath temperature, and the same relative gum contents for a series of gasolines will be obtained as at any other chosen bath temperature and volume evaporated. Results by this method should be equally significant as regards gum deposition in the engine, as would results at any other temperature and volume evaporated.

Two air-jet methods have been investigated; namely, the steam-bath and the liquid-bath 200-deg. cent. (392-deg. fahr.) air-jet methods, and both have been shown to be convenient and reproducible. The steam-bath method gives results which are double those obtained in a liquid bath at 200 deg. cent.,

but 20 hr. additional heating is required. The liquid-bath method at 200 deg. cent. only requires an additional 15-min. heating in the bath, and the objection to the small weight of gum measured can be largely offset by evaporation of 100-ml. volumes. A liquid bath maintained at about 200 deg. cent., therefore, appears to be preferable; but further work should be done in obtaining the most suitable bath liquid for this temperature.

Discussion

Harold S. Davis[1]:—This discussion relates mainly to that part of the paper, as originally preprinted for discussion, which reads as follows:

"As mentioned earlier in this paper, an indirect method was employed for studying time of evaporation, in which various volumes of each gasoline were evaporated to dryness and the gum content per 100 ml. obtained corresponding to evaporation of an infinitesimal volume of gasoline. The results were in accord with the equation

$$W_V = b\ (100 + V) \qquad (4)$$

where W_V is the weight of gum computed on a basis of 100 ml., V is the volume evaporated, and $100b$ is the weight of gum per 100 ml. obtained on evaporation of an infinitesimal volume. A decrease in the time of evaporation brought about by changes in the volume evaporated largely affects the time during which gum-forming constituents in the gasoline can change to gum in the evaporation process. In order to investigate this point, a number of blends of several gasolines were prepared by adding a gum-free gasoline in various proportions. Fifty-ml. portions of each blend were evaporated and by extrapolation the gum content per 100 ml. and per 100 per cent original gasoline was obtained corresponding to evaporation of an infinitely dilute blend of each gasoline. The results were in accord with the equation

$$W_P = a\ (200 + P) \qquad (5)$$

where W_P is the weight of gum computed on a basis of 100 ml. and 100 per cent, P is the percentage of original gasoline in the blend, and $200a$ is the weight of gum per 100 ml. and 100 per cent obtained on evaporation of 50 ml. of an infinitely dilute blend.

"Combining equations (4) and (5) to cover the effects both of volume evaporated and of dilution, there results

$$W = c\ (100 + V)\ (200 + P) \qquad (6)$$

where W is the weight of gum per 100 ml. and per 100 per cent obtained on evaporation of any volume V of a blend containing any percentage P of the original gasoline, and $20{,}000c$ is the gum content per 100 ml. and per 100 per cent which would be obtained on evaporation of an infinitesimal volume of an infinitely dilute solution."

Equations (5) and (6) Analyzed

The combined equation, (6), for application to results by the air-jet method, has already passed into the literature on this subject as equation (10) in a previous paper from the Bureau of Standards[2]. Accordingly, although the present discussion was originally based on the accompanying Bridgeman and Molitor paper as it was preprinted, it appears to be still pertinent.

No objections are raised against equation (4); that is, $W_V = b\ (100 + V)$.

Equation (5), that is, $W_P = a\ (200 + P)$, is not substantiated by experimental evidence. Proof is offered herein that the experiments on which it was based contained the same variables as those from which equation (4) was derived.

Table 1—Steam-Oven Gum-Tests

	Actual Volume Evaporated, Ml.	Observed Gum, "G", Grams		Calculated Gum[a], "G", Grams	Difference
Small-Dish (75-ml.) Tests					
10 ml. of gum-containing gasoline	10	10.7 12.0 13.0	11.9	(11.9)	
10 ml. of gum-containing gasoline + 10 ml. of straight-run Pennsylvania gasoline	20	11.5 11.7 11.4	11.5	10.8	+0.7
10 ml. of gum-containing gasoline + 40 ml. of straight-run Pennsylvania gasoline	50	11.3 11.3	11.3	11.9	−0.6
Large-Dish Tests					
10 ml. of gum-containing gasoline	10	10.9 10.8	10.9	(10.9)	
10 ml. of gum-containing gasoline + 40 ml. of straight-run Pennsylvania gasoline	50	8.6 9.8	9.2	10.9	−1.7
10 ml. of gum-containing gasoline + 90 ml. of straight-run Pennsylvania gasoline	100	9.2 9.3	9.3	13.9	−4.6
50 ml. of straight-run Pennsylvania gasoline	50	1.2			

[a]Calculated (from the values obtained on evaporating 10 ml.) by the Bridgeman-Molitor equations $W = c(100 + V)\ (200 + P)$ and $W = 10{,}000G/PV$. In these, W equals the milligrams of gum per 100 ml. of gumming gasoline; V, the volume, in milliliters, of gasoline actually evaporated; P, the percentage by volume of the gum-containing gasoline in the mixture actually evaporated; G, the milligrams of gum actually obtained; and c, a constant for each gasoline.

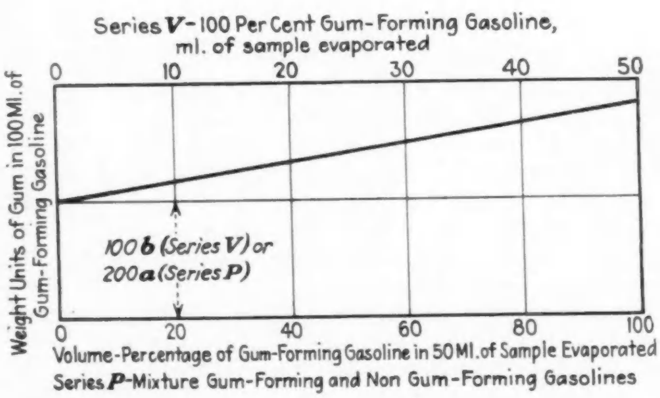


Fig. 1—Similarity of Equation (4) and Equation (5)

[1] Research and development department, Vacuum Oil Co., Inc., Paulsboro, N. J.

[2] See *S.A.E. Transactions* vol. 26, p. 488; A Further Study of the Air-Jet Method for Determining Gum in Gasolines, by O. C. Bridgeman and E. W. Aldrich.

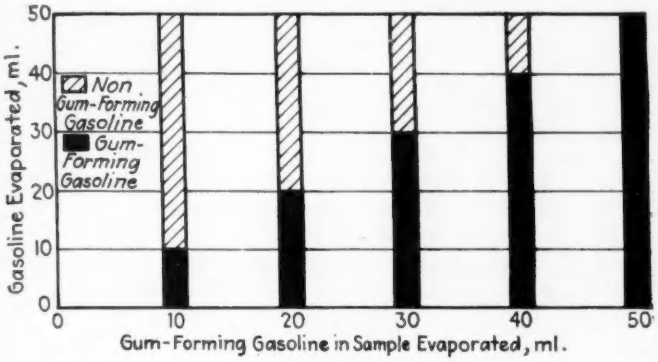


Fig. 2—Identity of Conditions in *Series V* and *Series P*

The combined equation, (6), that is, $W = c\,(100 + V)\,(200 + P)$, is incorrect.

This discussion will be limited to data taken from the records of the Vacuum Oil Co.[3]. Fortunately, the experiments were all made by one observer, J. C. Molitor, working continuously on the problem so that variations due to changes in apparatus and procedure were minimized.

The simple valuable relation given in equation (4), $W_V = b\,(100 + V)$ was based on experiments which are designated here as *Series V*. In these, various volumes of the individual gasolines were evaporated; that is, 60, 50, 40, 30 and 20 ml. The relation was found to hold for both the air-jet and the steam-oven methods.

Equation (5), $W_P = a\,(200 + P)$ was based on experiments by the steam-oven method, designated here as *Series P*, in which 50-ml. samples were used. These samples contained 100, 80, 60, 40 and 20 per cent, respectively, of the gumming gasoline.

If the values for "W" obtained by these two methods on any one gum-forming gasoline are plotted against the volumes of this gasoline actually used in the separate tests, then the curves for both series are identical. See Fig. 1, herein. This raises the thought that the gum-forming variables in the two series are really the same. That this might indeed be the case can be seen from Fig. 2, herein. The shaded areas represent the volumes of undiluted gumming gasoline used in the tests of *Series V*. The total areas represent the total volume of gasoline, 50 ml., used in each of the experiments of *Series P*, and here again the shaded parts represent the contents, in milliliters, of gumming gasoline. It is evident that the second series (P) did not test the effect of dilution only, because the quantity of gumming gasoline was also changed. *If the presence of a variable quantity of non-gumming gasoline does not affect the quantity of gum that is obtained from a given volume of gumming gasoline,* then the gum-forming conditions in the two series of experiments were identical.

To test this question, the experiments shown in Table 1 were carried out. It will be seen that, within the limits of error, the quantity of steam-oven gum left by 10 ml. of a gumming gasoline was not changed when 10, 40 or 90 ml. of non-gumming gasoline were added to the samples before evaporation. This confirms the thought expressed in the preceding paragraph, that the gum-forming variables in the two series of experiments (V and P) are identical. The experiments in *Series P* give no proof that dilution is a factor in gum formation as expressed in equation (5). Equations (4) and (5) should not be combined.

[3] The data, in part, were collected in a paper entitled The Determination of the Gum Content of Gasolines, by J. C. Molitor, which was presented before the Petroleum Section of the American Chemical Society at Indianapolis, Ind., in April, 1931, but was later withdrawn from publication.

The combined equation (6), $W = c\,(100 + V)\,(200 + P)$, appears to be incorrect both from the reasoning above and from the results given below.

Gum determinations had been made on 50-ml. samples of various gumming gasolines. Then, by using equation (6), the quantities of gum that would be obtained from 25 ml. of their 50-per cent blends with a non-gumming gasoline had been calculated. The results agreed well with those found experimentally and the conclusion had been drawn that "This direct proof of the equation $W = c\,(100 + V)\,(200 + P)$ furnishes further evidence of its validity and it can be assumed satisfactory for steam-oven determinations at 165 deg. cent. oven temperature." However, if the quantities of gum for the 25-ml. samples are calculated by the use of equation (4), $W = b\,(100 + V)$, that is, on the assumption that "W" is a function of the quantity of gumming gasoline only, then closer and very striking agreements are obtained as set forth in Table 2. In the first place, the average of the deviations is lower, 1.08 mg. compared with 1.28 mg. as stated in Cols. 5 and 4; next, the average of the calculated values for the gum, 7.82 mg., is almost identical with that of the experimental values, 7.85 mg. On the other hand, the average of the values calculated by the combined equation, (6), or 7.34 mg., is 7.6 per cent lower. This lower result represents, of course, the difference between the two equations

$$\frac{G\,(V = 25,\ \ P = 50)}{G\,(V = 50,\ \ P = 100)} = 0.1875, \text{ using equation (4)}$$

$$\frac{G\,(V = 25,\ \ P = 50)}{G\,(V = 50,\ \ P = 100)} = 0.1733, \text{ using equation (6)}$$

$$\text{Difference} \qquad = 0.0142, \text{ or } 7.6 \text{ per cent.}$$

Table 2—Steam-Oven Gum Determinations[a]

	G, in Mg.	G_1, in Mg.	G_2, in Mg.	$(G_1 - G)$, in Mg.	$(G_2 - G)$, in Mg.
	7.2	4.9	5.3	−2.3	−1.9
	3.2	1.9	2.1	−1.3	−1.0
	4.2	5.4	5.7	+1.2	+1.5
	2.2	1.5	1.6	−0.7	−0.6
	2.9	3.7	4.0	−0.8	+1.1
	4.1	4.3	4.6	+0.2	+0.5
	4.8	5.4	5.8	+0.6	+1.0
	5.4	6.2	6.7	+0.8	+1.3
	6.4	7.9	8.5	+1.5	+2.1
	8.2	6.7	7.2	−1.5	−1.0
	10.5	8.9	9.6	−1.6	−0.9
	14.1	12.6	13.6	−1.5	−0.5
	10.5	8.4	9.5	−2.1	−1.0
	14.1	13.6	14.6	−0.5	+0.5
	19.8	17.2	18.5	−2.6	−1.3
Total	117.6	108.6	117.3		
Average	7.85	7.34	7.82	1.28	1.08

[a] Volume of gasoline evaporated, (V) = 25 ml.; percentage of gumming gasoline in sample, (P) = 50.

G = gum, in milligrams, actually found.

G_1 = gum, in milligrams, calculated by the combined equation $W = c(100 + V)\,(200 + P)$ from gum values on 50-ml. samples, where $V = 50$ and $P = 100$.

G_2 = gum, in milligrams, calculated by the simple equation $W = b(100 + V)$, from gum values where $V = 50$ and $P = 100$.

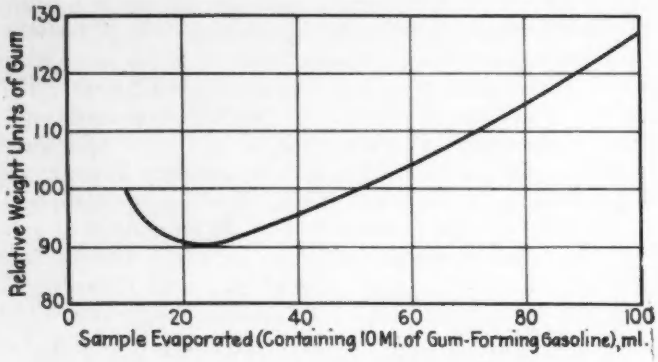


Fig. 3—Effect of Dilution on Quantity of Gum According to the Equation $W = c(100 + V)\ (200 + P)$

The agreement of the data, under the test of such calculations, is a testimonial to the skill of the operator, J. C. Molitor.

A further test of the combined equation is given by the direct dilution experiments, Table 1. For, according to this equation, if the quantity of gumming gasoline (here 10 ml.) is kept constant, then both "*W*" and "*G*" (actual milligrams of gum obtained) should change, on dilution with non-gumming gasoline, according to the peculiar curve shown in Fig. 3, herein. After a preliminary *decrease,* "*G*" would increase practically in proportion to the volume of non-gumming gasoline added and become infinite when an infinite quantity was added. This is, of course, absurd. There appear to be no theoretical or experimental bases for the combined equation (6).

O. C. Bridgeman:—It is pleasing to note that the data presented by Dr. Davis show quantitatively the same trends with volume evaporated and with dilution as do the Bureau data. I am entirely in agreement with Dr. Davis that the combined equation given in the previous paper (S.A.E. TRANSACTIONS, 1931, p. 488) is less logical than the simple equation containing only the volume of undiluted gasoline evaporated. However, it should be pointed out that there is insufficient information available to derive either equation rigorously. Both equations give exactly the same numerical values when applied to all of the Bureau results, due to the fact that $P = 100$ in all of the volume series and that $V = 50$ in all of the dilution series. With other values of the variables, a differentiation might be possible and the results presented by Dr. Davis suggest that the combined equation may be inaccurate. The important thing, however, is that both equations lead to the same general conclusion, namely that the relative gum contents of any two gasolines are independent of the volume evaporated or of the degree of dilution with a gum-free gasoline.

Special Motor-Vehicle Tax Apportionment

SHOULD the base or the rate of taxation or many other regulations affecting the operation of motor-vehicle equipment be fixed by law or should they be included in a code or codes backed by a general law so drawn that the codes may be modified to meet changing conditions and the development of the art without the necessity for submitting these technical and economic details to legislative debate and compromise? Such a course should lead to a greater degree of uniformity between states, not necessarily to a uniform rate of taxation, for conditions vary greatly, but to a uniform basis such as has already been determined by the Bureau of Public Roads, the American Association of State Highway Officials and individual engineers and economists and approved by the Joint Committee of Railroad Executive and Highway Users, the National Transportation Committee, and the National Automobile Chamber of Commerce.

I am in favor of the recommendation made by the Joint Committee of Railroads and Highway Users on the subject of motor-vehicle taxation. Summarized, this is as follows:

"The apportionment of special taxes among motor vehicles of various types should be based upon the use by each of the highway facilities required and should be sufficient to pay their fair share of total annual highway costs consisting of administration charges, maintenance expense, interest charges on highway debt and amortization of capital expenditures. Separate schedules should be determined for passenger automobiles, buses and trucks. There should first be determined the basis cost of constructing and maintaining a given highway designed for private passenger vehicles and other vehicles commensurate therewith. All vehicles should pay their share of such total as a base tax. Then the total additional cost of the construction, improvements and maintenance necessary to make a road suitable for a particular type of vehicle requiring such additional cost should be shared by each vehicle of that type and by each vehicle of greater size. Thus, each group should share in the base cost plus all increments of cost up to and including that required by it. The contribution of each group would be:

"(1) For passenger automobiles—by a registration fee, graduated according to weight or horsepower, and a gasoline tax.

"(2) For buses and other vehicles carrying passengers for hire—by a registration fee, based on mileage operated and graduated according to seating capacity, and a gasoline tax.

"(3) For trucks—by a registration fee, graduated so that it will increase more than directly with weight, and a gasoline tax."

It will be noticed that, under Item 3, truck fees increasing more than directly with weight are contemplated. This may occasion objections from some quarters on the basis that the use of the taxation function to perform the purposes of regulation or limitation is improper. With this I am quite ready to agree. However, inasmuch as the larger trucks are always in the minority, it will be found that the increment of highway expense necessary to accommodate these larger trucks will be distributed progressively between smaller and smaller numbers of vehicles as their gross weight increases, which will automatically serve to increase the rate of tax in greater proportion than the increase in weight.

This affords us one other particular in which the present basis of motor-truck taxation is to be severely condemned. Of course, the proceeds of all motor-vehicle-registration fees and special taxes should be devoted to highway purposes. There should be no diversion of such monies to any other purpose.

—Excerpts from a recent Metropolitan Section paper by David C. Fenner, Chairman of the Motor Vehicle Conference Committee, New York City.